PRR Shorlodge

IMPACT

of science on society

Vol. VI, No. 1
March 1955 Price per copy: $ .50; 2/6; 125 fr.

IN THIS ISSUE:

PERIODICAL
READING ROOM

Scientific Thought and Revolutionary Movements
by DAVID THOMSON

The Possibilities of Soilless Cultivation
by J. W. E. H. SHOLTO DOUGLAS

Blood Groups and Racial Groups
by A. C. ALLISON

IMPACT *of Science on Society*
quarterly

Annual subscription:
$1.75; 9/6; 450 fr.

Any of the National Distributors listed at the end of this number will accept subscriptions; rates in currencies other than the above will be supplied on application to the National Distributor in the country concerned.

When notifying change of address please enclose last wrapper or envelope.

© UNESCO 1955
NS 55 I 18A

UNITED NATIONS EDUCATIONAL, SCIENTIFIC
AND CULTURAL ORGANIZATION
19 Avenue Kléber, Paris-16e, France

Contents

SCIENTIFIC THOUGHT AND REVOLUTIONARY MOVEMENTS
by DAVID THOMSON 3

The forces seeking political and social change tend always to establish strong affinities with the ideas which are most novel or which are changing most rapidly. And because, in the years between the French Revolution and the formulation of Marxism, the ideas which were changing most rapidly were scientific ideas, science must be considered as one of the strong and constant influences on the birth and growth of modern revolutionary movements.

THE POSSIBILITIES OF SOILLESS CULTIVATION
by J. W. E. H. SHOLTO DOUGLAS 30

The general food problem is as far from being solved as ever, and it is likely to remain so until new methods of producing food in the areas where it is most needed are introduced on a large scale. One of the most promising of the new methods is hydroponics or soilless cultivation. By divorcing food production from the soil, it enables countries lacking fertile farmland to grow all the crops they need to nourish their people. The introduction of hydroponics on a large scale can provide the solution to the problem of local hunger.

BOOKS AND PUBLICATIONS
Blood Groups and Racial Groups 51

A. E. MOURANT, *The Distribution of the Human Blood Groups.*

Dr. Allison's short essay on blood groups and their practical applications in the fields of medicine, physical anthropology, and medico-legal practice.

CONTENTS OF PRECEDING ISSUES

Vol. V, No. 1, March 1954

Science and the Prevention of Crime, by OLOF KINBERG

Local Energy Sources for Underdeveloped Areas, by E. W. GOLDING

The Right to Scientific Property: a Unesco report

Vol. V, No. 2, June 1954

Scientific Progress and the Evolution of International Law, by CHARLES ROUSSEAU

The Human Element in the Application of Science, by J. R. GASS

Photosynthesis and Algal Culture, by D. NEVILLE-JONES

Machines and Men, by R. M. GOODWIN

Vol. V, No. 3, September 1954

Science and the Press, by WILLIAM E. DICK

Organizing for Applied Research in the Civilian Field, by J. KNOX

Scientific Calvinism, by A. C. ALLISON

Vol. V, No. 4, December 1954

Scientific and Social Aspects of Modern Medicine, by HENRI PEQUIGNOT

CB
478
a1
234

SCIENTIFIC THOUGHT AND REVOLUTIONARY MOVEMENTS

by

DAVID THOMSON

Dr. Thomson, Fellow and Director of Studies in History at Sidney Sussex College, Cambridge, and University Lecturer in History at Cambridge, is the author of several historical works, in particular Democracy in France: The Third and Fourth Republics, *London, 1946,* The Babeuf Plot, *London, 1947, and* Equality, *London, 1949.*

Does the growth of scientific knowledge in itself help to determine the purposes which it is made to serve? We are familiar enough with the idea that any particular achievement of science, however far-reaching may be its potential effects upon social conditions and human life, is itself ethically and politically neutral. Science, it is said, merely puts larger resources of power at man's disposal: the use to which man chooses to put that power is a matter of ethics and politics. This generalization is clearly enough true for any one material 'discovery' of science, in any particular set of social and political conditions. But is it equally true of the accumulation of scientific knowledge over the last two centuries? Have not the ethical and political beliefs prevalent in modern societies been themselves fundamentally affected not only by scientific ideas, but also by the methods and principles of scientific research? If so, has science in this sense favoured revolutionary or authoritarian movements—or both equally and indiscriminately? Unless the growth of science, in these terms of more long-range historical perspective, can be shown to have been ethically and politically 'neutral'—or at least ambivalent —it is of doubtful accuracy to claim that any particular advance in scientific knowledge is neutral.

Until the present century it was generally expected, by scientists and by most progressive opinion, that the advance of science would bring such obvious benefits and advantages to mankind that it would shape society and politics into forms which would favour further scientific research. It was assumed that because science makes 'progress', it therefore favours 'progressive ideas'; and that the freedom of thought, experiment and expression which scientists demand would inevitably reinforce democratic political movements favouring such conditions of freedom. The disillusionment which came with experience of modern political tendencies was expressed ironically by G. H. Hardy, in his well-known claim for pure mathematics: 'This subject has no practical use; that is to say, it cannot be used for promoting directly the destruction of human life or for accentuating the present inequalities in

the distribution of wealth.' Not only has it become plain that ethical beliefs and political systems are shaped by many factors other than scientific ideas and progress; but it is also clear that scientific research requires order and organization no less than freedom, and in its most highly organized forms may seek alliance with authority, which alone can provide the monetary resources and material equipment it needs. Scientific ideas may strengthen arguments in favour of government by an elite or a technocracy, at the expense of democratic ideals of government by consent; just as scientists themselves, being par excellence specialized experts, may develop a bias in favour of rule by experts. These unexpectedly anti-democratic tendencies of science have been examined, in one of their aspects only, by Professor F. A. Hayek in *The Counter-Revolution of Science*.[1]

Professor Hayek concerns himself especially with positivism, and with the undemocratic effects of transferring some of the concepts and methods of the natural sciences to the study of the social sciences. He maintains that such transference was illegitimate because it was fallacious, and gives, as a sub-title for his book, *Studies on the Abuse of Reason*. But even the fallacious transference of ideas from the physical to the social sciences sometimes favoured revolutionary movements rather than counter-revolutionary movements; and the road to freedom, no less than the road to serfdom, has been paved with ethical ideas and political theories derived from the quarries of science. It is perhaps significant that Professor Hayek does very much less than justice to the revolutionary political influence of Condorcet at the beginning of the period he studies, and that he stops short at discussion of the political influence of Darwinism. Darwinism was made to lend as much support to the mild socialistic movement of the Fabians, with their faith in 'the inevitability of gradualness', as to the more authoritarian champions of militarist nationalism and imperialism, who found therein reinforcement of their belief in eternal struggle and survival of the strongest.

The total impact of scientific ideas on ethics and politics (as on all the social sciences) has, indeed, been mixed; it has in some ways favoured democratic and revolutionary movements, in other ways authoritarian and counter-revolutionary movements. Whether these contrary effects have, on balance, neutralized one another it is impossible to say, if only because historical research has so far been very deficient in exploring the whole matter of the impact of scientific ideas on ethics and politics. It is impossible here to do more than suggest some of the crucial points at which the relationship between scientific ideas and revolutionary movements can be revealed; but at least it is possible to show that this relationship is organic and important, and worthy of much closer attention than it has so far received.

1. Reviewed in this journal, vol. IV, no. 2, 1953.

THE REVOLUTIONARY MOVEMENT OF DEMOCRACY

The modern world has become so used to thinking of democracy as something established and even on the defensive, as an order already in being and 'challenged' by movements of fascism or communism, that it is well to recall that in eighteenth-century Europe and America democracy proved to be the greatest revolutionary movement in history since the coming of Christianity. There had been revolts enough, and there had been the great religious upheaval of the Reformation. But never before had an ideology gained such general support in challenging the whole basis of assumptions, traditions and institutions on which political life rested. The powers of feudal nobility, church and monarchy had varied considerably in their relative effectiveness, but no important movement of any kind had questioned the right of any or of all of them to exercise authority in government and jurisdiction. In only a few countries, most notably Britain and the Netherlands, had the wealthy middle classes asserted in any institutional way their right to have a share in this authority; although monarchs, including even that paragon of all monarchy, Louis XIV of France, had called upon middle-class men like Colbert, the son of a draper, to serve as ministers of state. But the notion that all subjects were citizens with equal rights to a share in political power and that the state should be so organized that it rested upon the consent of the whole body of citizens and should even express their 'general will': that was the greatest and most radical challenge to the whole existing social and political system. Yet that, and no less, was what the democrats of the later eighteenth century asserted, whether in the American Declaration of Independence or in the French Declaration of the Rights of Man and of the Citizen.

There is even a sense in which nearly all important revolutionary and reforming movements of later times have been developments of this fundamental challenge. In this sense most totalitarian movements of the twentieth century have rested not on any new revolutionary impulses, but rather on attempts to side-step or frustrate the revolutionary implications of democracy, and to evade the consequences of universal suffrage. They reverted in effect to the oldest and most discredited system of government in human history: personal and party despotism owing no responsibility to the governed. They were, in the most complete and literal sense, not revolutionary but reactionary. Nineteenth-century Marxism, in so far as it sought to increase social equality and economic liberty for those who did not enjoy such equality or liberty in capitalist society, shared in the genuine revolutionary impulses of the democratic ideal.

This broad revolutionary movement of the last two centuries flows from the great tide of liberal-democratic ideas, generated in the eighteenth century and first breaking upon the *ancien régime* in the American and French

revolutions. In combination with the economic and social transformations wrought by the industrial revolution, this tide of liberal-democratic ideas produced a further current of social-democratic ideas; and both, mingling with the insurgent dynamic forces of nationalism which were released by the French Revolutionary and Napoleonic Wars and their aftermath in Europe, can be watched surging tumultuously through one country after another during the following 150 years. When the tide of revolutionary ideas lapped the borders of the East it produced the Russian revolutions of 1917: first the Liberal Revolution which overthrew Tsardom, and within six months the Bolshevik Revolution.

The gravitational pull which began this side of revolution came first from the rationalist philosophy of the eighteenth century. In the ancient and highly traditionalist society of Western Europe, and particularly in France as the greatest and most influential country of Western Europe, religious and ethical beliefs, no less than political and social institutions, were subjected to new tests of value and purpose. Voltaire and the Encyclopaedists, Montesquieu, Rousseau and all the *philosophes,* brought to bear upon the *ancien régime* a devastating rationalist critique which made inevitable first a reorientation of opinion and then a reorganization of society. Much has been written about how this rationalist philosophy came to transform ethics and politics.[1] But remarkably little has been written about the precise connexions between this rationalist philosophy itself and the changes in scientific thought which began with the so-called 'scientific revolution' of the seventeenth century. It is clear enough that this scientific revolution, hinging upon the work of Galileo, Descartes and Newton, encouraged a fresh intellectual outlook, a new bias of mind which valued the collection of verifiable data, and promoted a spirit of inquiry, a critical habit of mind and the search for underlying 'laws of nature'. It is unlikely to be mere coincidence that France, the main fountain-head of rationalist thought during the eighteenth century and of revolutionary ideas and movements at the end of that century, was also the home of Cartesianism and the leader of the world in the progress of science. Some direct connexion and affiliation is to be expected. But can it be shown more precisely what this connexion was, and how it affected the character of the revolutionary movement which was born of rationalist philosophy?

THE ROOTS OF RATIONALISM

The foundation of the Royal Society in England in 1660, and of the *Académie des Sciences* in France in 1666, was some indication of the interest of

1. e.g. Daniel Mornet, *Les origines intellectuelles de la révolution française,* Paris, 1934; Philippe Sagnac, *La formation de la société française moderne,* Paris, 1945-46, vol. II; Kingsley Martin, *French Liberal Thought in the Eighteenth Century,* London, 1929, to mention only three out of many such studies.

authority in the new knowledge being accumulated by scientists. There seems to have been very little realization that it might have any revolutionary consequences for politics, and at first indeed it had none. Almost exactly a hundred years before the French Revolution began, so perceptive a Frenchman as La Bruyère could remark, in all innocence of the scientific revolution already taking place: 'Everything has been said, and we arrive too late at the end of seven thousand years during which thinking men have been in existence. . . . We must simply aim at thinking and speaking rightly, without trying to convert others to our point of view.' Fifty years earlier the mathematician and philosopher, René Descartes, had written his *Discours de la méthode,* prescribing a geometrical method by which the reasoning power of the individual could arrive at knowledge of truth. It was ultimately this Cartesian philosophy, based on belief in the capacity of mathematical methods of reasoning to find truth, which was to ensure that the scientific revolution should have profound political repercussions. The total re-thinking necessitated by the discoveries of Galileo and Newton can scarcely be better expressed than by Descartes's own principle: 'To reach the truth one must, once in one's life, dispense with all received opinions, and reconstruct anew and from the foundations all one's systems of knowledge.' The crucial link between the scientific revolution and the ideas of the *philosophes* so readily adopted in the French Revolution was the inherent conflict between this Cartesian attitude and a social and political order based on traditional authority, custom and privilege. To assess the impact of science on the liberal-democratic revolutionary movement it is not necessary to show that eminent scientists were revolutionaries, although some of them were; nor that the revolutionary movement transferred (however fallaciously) the concepts of the natural sciences to theories about society, although it did. It is only necessary to examine some of the mediations by which this revolution in scientific knowledge of the world and of the universe compelled men to re-think fundamentally their expectations from social life and government.

Fontenelle has been described as 'the most important single link between the scientific revolution and the *philosophe* movement'.[1] As secretary to the Académie des Sciences, from 1699 until 1741, he used his official funeral orations on the scientists of the period as a vehicle of propaganda for science. He emphasized the role of Cartesianism, and in particular of geometry, in the transition from theological to scientific habits of thought. In 1686 he wrote the first great work designed to popularize science, his dialogue on *The Plurality of Worlds,* and succeeded in making it amusing and attractive to the *beau monde* of his day. (Newton's *Principia* appeared in the following year.) Fontenelle had little personal eminence as a mathematician or scientist; but as a literary man with enough *esprit* to capture a wide reading public he

1. Herbert Butterfield, *The Origins of Modern Science, 1300-1800,* London, 1949, p. 144.

translated scientific thought into a new view of the universe and a new outlook on life. The conquests of reason, as transmitted by Fontenelle and his literary successors, the *philosophes,* were presented as almost the victory of common sense. It came to be believed that the mathematician or the scientist achieved his results not by the use of genius or a mysterious learning, but by the systematic application of a quality of mind which most men might possess. In this sense 'reason' was universal—the unique and unifying possession of mankind.

The universalism and cosmopolitanism of the *philosophe* movement, which was its chief characteristic politically, sprang from this faith in the universal rationality and intelligence of man. It was capacity to use intelligence and reason that made man the same 'from China to Peru'. At first 'enlightenment' seemed so universally acceptable that men like Voltaire or the young Jeremy Bentham looked not to universal suffrage or democracy to achieve it, but to 'enlightened despotism'. The support of so many of the *philosophes* for the eighteenth-century monarchs who adopted and fostered 'enlightenment' rested on impatience and acceptance of a short-cut; the masses, in the days before public education, were so conspicuously far from enlightenment that to rationalize government from above seemed the only practicable course. Once royal governments were persuaded to adopt scientific methods of administration and to seek the welfare of their peoples, the rule of reason would spread. Moreover, since the power of the priesthood seemed to the *philosophes* the very bulwark of popular superstition and ignorance, alliance with authority was needed to destroy this power. *Ecrasez l'infâme* was the immediate aim of the earlier rationalists: and *l'infâme* meant not only the Church but superstition and intolerance everywhere.

The temporary alliance between the *philosophes* and enlightened despotism yielded some reforms. Frederick the Great of Prussia abolished serfdom and persecuted no one on account of his religious beliefs. Catherine the Great of Russia abolished—at least formally—the use of torture. But when Joseph II of Austria pressed his enlightenment further, his benevolence produced revolt. There was a limit to what kings could achieve for the *philosophes,* because they could not completely free themselves from the traditions of hereditary monarchy, feudal aristocracy and irresponsible government. Their reforms neither forestalled revolution nor prevented the growth of democratic ideas. Indeed, as fuller knowledge of social evils and of democratic ideals spread, the enlightened despots found that they had been digging their own graves.

It was not that the *philosophes* were themselves revolutionaries. It would be wrong to think of the rationalist movement in the eighteenth century as consciously directed towards producing revolution. The rationalist intellectuals who contributed to the *Encyclopédie* of Diderot contemplated no political action which would destroy the regime. Some expected further

reforms from the regime itself; others, like Rousseau, who envisaged an idyllic new order put it into an indefinitely remote future. They were propagandists against superstition and the power of priests, on behalf of the new ideas suggested by the discoveries of science and propounded by rationalist thinkers. In this respect their influence was similar in kind to that of the scientists themselves; and indeed science had not yet come to be regarded as a specialized way of seeking truth, distinct from moral philosophy or theology. Even the French word *science* retained its wider meaning of 'knowledge' in general. Knowledge was not yet departmentalized, and 'philosophy' comprised any sort of examination of the physical world, of man as a biological or moral or economic entity, and of man's organization into societies and states. The great *Encyclopédie* was itself a symbol of their continued belief in the unity of knowledge, and a conscious effort to prevent its disintegration. It appeared both natural and inevitable to apply similar principles to the investigation of human thought and activity in all their forms; it would scarcely have occurred to them to do otherwise. Even theology was comprised within the corpus of 'knowledge' for as long as possible; and just as Descartes had been prepared to deduce the whole universe from God by mathematical logic, so the *philosophes* tended to be Deists, with only a few extremists like d'Holbach drawing inferences of atheism. Yet, given their rationalist hypotheses, this very insistence on the unity of human knowledge made the inherent clash between rationalism and the presuppositions of the social and political order all the more inevitable, and all the more revolutionary in its consequences.

As confidence in the efficacy of benevolent despotism declined, greater emphasis was put on education. The more it was concluded that progress demanded democracy, the more attention was given to the emancipating possibilities of public education. Because direct conflict arose with the established power of the Church over the schools, such education had to be positive education in rationalism. It has been a characteristic of all predominantly Roman Catholic countries to breed anti-clerical movements which are impelled to evolve a rival philosophy as comprehensive and complete as Catholicism itself. This tendency still further reinforced belief in the totality and unity of human knowledge; and positivism itself tended to become a religion, and to meet dogma with counter-dogma. The writings of Voltaire show clearly enough how religious persecution bred militant rationalism; Robespierre felt impelled to counter Catholicism with an alternative cult of the Supreme Being and of Reason, with a ritual and orthodoxy of its own; freemasonry encouraged a similar trend; and positivism, as interpreted by Jules Ferry in the Third French Republic, became as militant and intolerant as its clericalist enemy. Great Britain and the United States, where Protestantism had already broken the orthodoxy of Roman Catholicism, never developed rationalist or positivist movements of like militancy. Is it mere

chance that they, during the twentieth century, have increasingly overtaken France in the leadership of scientific research and thought?

THE DREAM OF UNANIMITY

One of the most important of the mediations by which scientific thought affected the democratic movement was also one of the most concealed. Scientific knowledge, it was noticed, gained acceptance by a kind of consensus of informed opinion. A scientific theory was accepted as true not only because the man who advanced it produced mathematical demonstration or experimental evidence to support it, but also because his fellow-scientists, having heard his demonstration and his experimental evidence, were convinced and lent it their support. Scientific truths ultimately elicited the unanimous agreement of all informed and enlightened opinion. It was natural, for the reasons suggested above, that rationalist thinkers should expect ethics and politics to be capable of eliciting similar unanimity. Reason was universal, and reason was one. The more the social order approximated to a rational or 'natural' order, the more it would reflect such unity and unanimity. Once men's understanding was undistorted by superstition and privilege, and all were recognized as equal in rights and freedom, then reason would reveal their natural harmony of interests. Little room would remain for honest differences of opinion, which would all be capable of being resolved by rational demonstration and persuasion. There would be a consensus of opinion in democracy closely akin to the consensus of opinion which lay behind scientific truth; and education would open the door to the necessary enlightenment and to ultimate unanimity. This startling and unduly neglected assumption of revolutionary democratic thought has its modern counterpart in the present-day insistence that, in British trial by jury, the members must be unanimous in their verdict. It is taken for granted that when an objective truth is being established—a question of guilt or innocence—then twelve honest persons, having listened to all the available evidence, will necessarily reach complete agreement.

There is abundant proof that such was the underlying expectation of the democratic movement in Britain, America and France. In his *Fragment of Government* in 1776 Jeremy Bentham declared that: 'Men, let them but once clearly understand one another, will not be long ere they agree.' In the same year the fathers of American Independence not only proclaimed that 'all men are created equal' and that man's inalienable rights include 'life, liberty, and the pursuit of happiness', but added the even more startling assertion that such 'truths' were 'self-evident'. William Godwin, in 1793, remarked of truth that: 'The more it be discovered, especially that part of it which relates to man in society, the more simple and self-evident will it appear.' In the

same year Condorcet formulated the same idea: 'Every correctly reasoning being will be led to the same conclusions, in ethics as in geometry.' Rousseau, in a revealing footnote to his *Contrat social,* noted the proviso that: 'To be general, a will need not *always* be unanimous'; and he added that for the general will of the community to find full expression 'each citizen should think only his own thoughts'.

This belief seems remarkable to a modern democrat accustomed to regard a free society as involving diversity of opinion, multiplicity of parties and associations, and a constant effort to find a working compromise between contrary viewpoints. It vitally affected the course of the revolutionary movement itself. It produced a certain fear of party politics, and a widespread distrust of political parties as mere factions hostile to freedom. 'If I could not go to heaven but with a party,' declared Thomas Jefferson, 'I would not go there at all.' The American Constitution, like the constitutions produced during the French Revolution, omits any mention of parties; and they were specifically condemned by George Washington in his Farewell Address: 'All combinations and associations under whatever plausible character, with the real design to direct, control, counteract or awe the regular deliberations of the constituted authorities, are destructive of this fundamental principle and of fatal tendency.' Because, under the *ancien régime,* the Church, guilds, corporations and *parlements* had appeared as vested interests obstructing the common good of the community as a whole, the early democrats regarded all organizations intermediate between the individual and the state as undesirable and reactionary. Corporations embodied what Bentham called 'sinister interests' and what Rousseau condemned as 'partial societies'. Accordingly, not only did democrats in Britain and America resist the formation and operation of political parties; but the Jacobins during the French Revolution nationalized the Church, prohibited the old corporations, and in the Le Chapelier Law of 1791 (which remained operative until 1864) banned all professional or occupational societies. Universal suffrage was expected to make organized opposition unnecessary; and in politics, as in science, all honest and well-informed men would spontaneously arrive at a wide consensus of opinion. It was the middle of the nineteenth century before de Tocqueville could admit ruefully that 'parties are a necessary evil in free governments'; and John Stuart Mill, reversing the whole doctrine, could depict a free society as one where there existed the greatest freedom for the richest diversities of opinion. Even then, it seemed as 'self-evident' to Karl Marx as it had seemed to the American and French revolutionaries that political parties must represent partial interests hostile to the common good, and that the good society of the future would be without classes and therefore without parties. But Marx, paradoxically enough, shared their ultimate fear of politics, and looked forward to a time when politics would be eliminated because the government of men would

give way to the administration of things, and the organization of society would rest on truly 'scientific' methods and principles.

THE CASE OF CONDORCET

More precise detail of how this kind of mediation between scientific thought and revolutionary movements worked out in practice can be gathered from closer examination of the career of the Marquis de Condorcet (1743-94). He belonged to the galaxy of eminent mathematicians and scientists which made France of the later eighteenth century the home and focus of scientific progress. In a land which could then boast of scientists as eminent as Laplace, Monge, Lagrange, Lavoisier, Berthollet, Gay-Lussac, Lamarck and Bichat, Condorcet still remained eminent. His fellow-mathematicians counted him among the ten greatest geometers in Europe. At the age of 22 he presented to the Académie his essay on the integral calculus and became the protégé of d'Alembert, Helvétius and even the great Turgot himself. From 1769 he followed in the steps of Fontenelle, composing funeral orations on the seventeenth-century academicians; and from 1773 onwards he became secretary of the Académie des Sciences. He was brought into the state administrative service in 1774 when Turgot, as Minister of Finance, appointed him inspector-general of the mint. Exposed to the full influences of the *philosophes,* the encyclopaedists, the physiocrats and the rationalist thinkers of all kinds, partly through his personal friends and partly through his wife's *salon* (which Adam Smith attended), he became one of the main channels through which the thought of these intellectuals was brought to bear upon the revolutionary ideas of 1789. And it was his established eminence as a mathematician which brought him the public prestige that made possible his great political influence after 1789.

The part which he played personally in the course of the Revolution was considerable. As a journalistic popularizer of revolutionary democratic ideas, as a founder with the abbé Siéyès of the Société de 1789, as a member and later President of the Legislative Assembly of 1791, and as a member of the Convention of 1792, his personal influence on events was constant.[1] But the extent of this personal participation should not be allowed to obscure the influence which he exerted on the growth of revolutionary ideas in conjunction with his fellow-scientists. The famous masonic Loge des Neuf Sœurs, to which he belonged before 1789, included as members Voltaire, Benjamin Franklin, the physician Cabanis, the astronomer Lalande, and a score more members of the Académie. It was founded by Lalande and by the widow of Helvétius, and became a powerful focus for the scientists most

1. This is well described by Alphonse Aulard, *Histoire politique de la révolution française,* Paris, 1901.

directly interested in political reforms.[1] As well as being a friend of Benjamin Franklin, Condorcet came to know Tom Paine and in 1786 published a little study *De l'influence de la révolution d'Amérique*; a year later he translated into French the new federal Constitution of the United States. His connexions with the radical democratic movement in America were thus close, and ensured that his mind should turn early to questions of constitutional rights and institutions. In 1787-88 his reflections bore fruit in two works, disguised as comments on events in America but actually directed to French readers: *Lettres d'un bourgeois de Newhaven* and *Lettres d'un citoyen des Etats-Unis*. They discussed such matters as electoral laws, the powers of constitution-making, and the functions of the legislative and judicial powers. At the same time, the experiments of Turgot and Necker with municipal and provincial assemblies, and the decision to summon the States-General in 1789, made his reflections of immediate topical relevance to France. His influence on ideas of constitutional reform was thus present from the outset; and even more than Paine he formed a direct link between the American and the French Revolutions.

In 1789 he published his *Essai sur la constitution des assemblées provinciales,* in a postscript to which he expressed the gravest anxieties about the outcome of summoning a national assembly when the electorate was so inexperienced and so ill-informed about political matters. He pinned his hopes on the speedy formulation of a 'declaration of the rights of man and the citizen', urging the American experience as a guide. Such a statement of general rights and principles would, he held, serve as a guide and as a barrier against the abuses of power. This essay was followed by a series of pamphlets designed to influence the opinion and conduct of electors and elected. They included a proposed draft declaration, set out like a geometrical proposition; and though it was not followed by the National Assembly when it issued its own version some months later, Condorcet had a further opportunity, in 1793, to present a fuller and more realistic version as the *rapporteur* of the Constitutional Committee of the Convention. The idea of setting out general assumptions and propositions before proceeding to the detailed enactment of the Constitution was a characteristic geometer's adaptation of the American procedure. That earlier geometer, René Descartes, would have thoroughly approved.

It was part of the distinction of Condorcet's thought that he avoided being doctrinaire and dogmatic in his application of mathematics to politics. He applied his mathematical knowledge to the electoral law and to methods of voting, and as early as 1785 he wrote an *Essai sur l'application de l'analyse à la probabilité des décisions rendues à la pluralité des voix*. But he thought

1. See Louis Amiable, *Une loge maçonnique d'avant 1789*, Paris, 1897, for a full account of this famous masonic lodge; and Frank Alengry, *Condorcet: Guide de la révolution française*, Paris, 1904, p. 19.

as much in terms of probabilities as of absolute certainties; and the relativity and probabilism of his thinking saved him from the worst fallacies of assimilating the social to the natural and mathematical sciences. In his most famous work of all, the *Esquisse d'un tableau historique des progrès de l'esprit humain,* which he wrote in 1793 under the shadow of the guillotine and which has been frequently acclaimed as a veritable summary of the thought of the whole eighteenth-century rationalist movement, he formulated his ideas in concise and memorable form. He particularly re-stated his theory of probabilism:

> The applications of the theory of probability are a token of how much they can contribute to the progress of the other sciences. They can determine the probability of the extraordinary and enable us to judge what should be rejected and what is worth verifying; they can show the likelihood of regular recurrence of these frequent phenomena met with in the practical arts of man which cannot in themselves be ascribed to any order already obedient to a general law: examples from medicine are the beneficial effects of certain remedies and the success of certain preservatives. . . . These applications have also taught us the several degrees of certainty we can expect to reach. . . . They show what are the advantages or disadvantages of the various forms of election, of the various ways of arriving at decisions by a majority vote; the several degrees of probability which can result therefrom; what degree the public interest must exact, having regard to the nature of the particular question. . . .[1]

With remarkable foresight, Condorcet also saw the possibilities of applying mathematical and statistical methods to social studies, and in particular to economics; his experience at the mint had already drawn his interest towards financial problems. The following passages show his imaginative insight into such future possibilities, which were to revolutionize methods of government in the nineteenth century and economic theory in the twentieth century:

> Then how valuable is the research into human expectation of life, and the influence on this expectation of sex, temperatures, climate, profession, government and habits of life; the mortality from different diseases, population changes, the relative degree of influence of the factors causing those changes; the distribution of population in each country in terms of age, sex, and occupation, how valuable are all these studies for our physical knowledge of man, for medicine and for public economy!
>
> Indeed, how widely has this theory been put to use in public economy, for the calculation of annuities, tontines, savings and provident funds, and insurances of all kinds!
>
> Again, is not the use of this theory necessary for that sector of public economy concerned with the theory of measures, and of money, banks, financial operations or imposts, and with their incidence established by law, the frequently very different real incidence and their reaction on all parts of the social system?[1]

This realization of the potentialities of more scientific administration and taxation had only one inference for those who had known the frustrations and muddle of public administration under the *ancien régime*: that only a republic was likely to introduce order into the chaos. It is not remarkable,

1. *Esquisse d'un tableau historique des progrès de l'esprit humain, Neuvième époque.*

therefore, that Condorcet was among the first to conclude that the experiments in constitutional monarchy would come to nothing, and to propound the need for a republic. It was he who, on 9 July 1791, after the fateful flight of the king to Varennes, made the first categorically republican speech and who pressed for universal suffrage and the use of the referendum.

The democratic revolution was destined not only to change the purposes of government, to insist that government should express the will of the community as a whole and serve the material interests of the community as a whole. It also transformed the methods of government and administration—a revolution no less radical and no less important in its implications. No man with experience of eighteenth-century administration could help believing in the merits of rationalizing it. But reforms in the judicial and penal systems, in the fiscal and financial systems, in the institutions of administration itself, seemed increasingly certain to be frustrated without a prior political revolution. The utilitarian reforms which Jeremy Bentham and his disciples were to fight for and so largely achieve in Britain demanded, in most European states, some form of republican or at least representative government; failing that, they could be achieved only by the centralized authority of a Napoleon, liquidating the remnants of the *ancien régime* along with the excesses of the revolution. The methods of measurement, statistical analysis, political arithmetic or what Condorcet called *la mathématique sociale,* were introduced by the rationalist and democratic revolutionary movement, along with the ideals of republicanism. They were equally a consequence of the impact of science on the revolutionary movement; though Napoleon utilized these new resources of power to serve his own ambitions and despotism. They were nevertheless indispensable to any liberal-democratic regime existing to serve efficiently the welfare and interests of the whole community.

When the French Revolution broke out, a second great revolution in scientific thought had just reached its culmination, and considerably reinforced belief in discoverable natural laws. The seventeenth-century revolution in mechanics, which was marked by the publication of Newton's *Principia* in 1687, was now followed by the eighteenth-century revolution in chemistry, marked by the publication of Antoine de Lavoisier's *Traité élémentaire de chimie* in 1789. The two-thousand-year-old theory that all substances are composed of four elements (earth and air, fire and water) and the more recent phlogiston theory were alike exploded, and Lavoisier—building upon the work of the great eighteenth-century British chemists, Boyle, Cavendish, Priestley and Black—showed that water and air are both composed of other elements, and that bodies burn by combining with the element oxygen, which forms one-fifth of the air. By revealing that nature had many more elements than had been suspected, Lavoisier opened up a vast new field for experiment and thought, and may be regarded as the founder of modern chemistry and of much of modern science.

Lavoisier was an exact contemporary of Condorcet (1743-94); and like Condorcet he was an academician, took a close interest in the applications of science to social life (especially to reforms in agriculture and industry), served the state as an administrator, and was condemned to the guillotine in 1794. Both men shared the views of the physiocrats, and wanted to free the farmer, the manufacturer and the trader from their economic burdens of inequitable taxation and excessive state regulation. Along with Condorcet, Lavoisier belonged to the Société de 1789 which sought to secure a new constitution. In 1790, when the Académie des Sciences was entrusted by the National Assembly with the task of devising a new system of weights and measures (later to become the metric system), the Commission it set up included Condorcet and had Lavoisier as its secretary and treasurer.

Like Condorcet, too, Lavoisier perceived the immense importance of public education in fitting a society for democratic government. He prepared for the Bureau of Consultation of Arts and Crafts a memorandum on national education, presented to the Convention in August 1793, at which he urged free primary education for all children as the basis for equality of opportunity, and (under the influence of the similar proposals put forward by Condorcet) emphasized the democratic need to educate the whole nation. Above all, Lavoisier reiterated the characteristic faith of the *savants* (reinforced anew by his own fundamental contribution to scientific thought) in the totality of knowledge, which meant that progress in one science aided and facilitated progress in another. All branches of science and technology, he maintained, are linked together, and it is not possible to make great progress in one without parallel and auxiliary progress in another. The geometer needs the astronomer and the physicist, just as they need the geometer. All scientists serve a common cause and have a common interest. They should and must work in collaboration. They are an army which must advance on an even front. All forms of knowledge are, indeed, threads in one great tapestry, and we are assured of an ultimate pattern, and design. So long as such a belief in the unity of all knowledge prevailed, the impact of scientific ideas on ethics and politics was bound to be direct and immediate.

THE NATURAL HARMONY OF INTERESTS

The conclusion to which all the considerations so far described irresistibly led the democratic revolutionaries was that in a 'natural society', just as there would be spontaneous unanimity about politics, so there would also be a natural harmony of interests. For a century to come no idea was to prove a more constant or a more revolutionary element in the thinking of liberal and social democrats alike than this many-sided concept.

The problem of how the interests of the community are related to the

interests of all the individuals within it was raised by the novel task of designing a government to serve efficiently the needs of the whole community. Could individual interests be completely reconciled with the interests of society as a whole? If so, would individual interests be automatically harmonized in a free society, or must it be the task of legislation to achieve harmony artificially? A medley of different answers could be devised. But the whole impact of scientific thought was directed towards strengthening and encouraging assurance that a harmony could, in one way or another, be achieved. As Condorcet put it:

> Has not the improvement of laws and institutions, resulting from the progress of these branches of knowledge, the effect of bringing together, of identifying, the interest common to each man with the common interest of all? Is it not the purpose of the art of social life to destroy this apparent antithesis?[1]

Just as Newton had discerned, behind the complex working of the universe, certain general laws or principles which governed the motion of all material bodies, and just as Lavoisier had revealed a new elemental pattern within the structure of nature, was it not likewise probable that great general principles of synthesis could be discovered behind the working of human society? Nature seemed to operate on many such laws, waiting only to be discovered by human intelligence and reason and used for the benefit of mankind. And in the notion of a general harmony of interests it was thought that such a 'law of nature' had been found.

In the context of the prevailing psychological theories inherited from Locke and Hume, individual interests were understood in terms of happiness. Individuals were assumed to seek their self-interest in the sense of desiring pleasure and avoiding pain. Such interests could be reconciled with the interests of others, and with those of society as a whole, in three possible ways. If one postulated a natural sympathy for others or a 'moral sense', one could argue that harmony came from the moral action of each individual in adjusting his conduct so as to promote the interests of the whole: and as Francis Hutcheson, the master of Adam Smith, put it, 'that action is best which accomplishes the greatest happiness for the greatest number'.[2] Alternatively, one might deny the existence of such a personal 'moral sense', but argue that harmony is produced artificially by the action of the legislator, who by a rational and ingenious system of rewards and punishments so plays upon the impulses of self-interest in each individual that he will be induced to behave in a way which serves the interests of society as a whole. This was the view most characteristic of Jeremy Bentham and the school of philo-

1. op. cit., *Dixième époque*.
2. Francis Hutcheson, *Inquiry concerning moral good and evil*, quoted by Elie Halévy, *The Growth of Philosophic Radicalism*, London, 1928, p. 14; a book which is a masterly analysis of the roots of utilitarian thought. Mr. Halévy writes: 'What is known as Utilitarianism . . . can be defined as nothing but an attempt to apply the principles of Newton to the affairs of politics and of morals.' (p. 6.)

sophic radicals or utilitarians in Britain. Thirdly, in much more optimistic vein, one could deny that either the individual or the state had to manipulate individual behaviour so as to produce harmony; and maintain that harmony would emerge automatically from the natural reasonableness of free men living in a rational or 'natural' society. This was the view mainly urged by Adam Smith in relation to economic life, and by all later liberal *laissez-faire* theorists about social life in general. It postulated a natural identity of interests, and was expressed paradoxically by Bentham in the argument that if each individual were always to promote the interests of his neighbour at the expense of his own, humanity could not survive for a single moment. The operation of the principle of self-interest was, in short, the great cohesive principle, comparable to the law of gravitation or attraction of masses, which held society together; and society rested on a self-operating mechanism.

These three possible variants of the concept of a natural harmony of interests, though logically distinct, were not clearly separated in the thought of the democratic revolutionaries. They were often held simultaneously by the same thinker. Thus Bentham, following Adam Smith, could argue in favour of there being a natural identity of interests in economic affairs, whilst also urging a more rational penal system whereby the state could secure an artificial reconciliation of interests in social and political affairs. Condorcet, as in the quotation given above, looked to good laws and institutions to reconcile the interests of each with those of all; but elsewhere he could use terms which presupposed an automatic identification of individual and social interests. In 1786 he wrote:

> It can be said in general, and in the same sense, that the interest of a nation is in accord with the common interest of all, just as it has been said that the interest of each individual, properly understood, is in accord with the common interest of society.[1]

They could, moreover, with suitable modifications, be combined into one comprehensive theory of ethics and politics; so that, whilst holding that there was a general tendency for individual and social interests to be partially identical and ultimately reconcilable, one could expect, from the double process of legislative pressure and moral regeneration, to achieve a complete harmony of interests in a fully rational society. This, indeed, was broadly the final argument of Bentham; and he significantly called his greatest work on the subject, which was published in 1789, an *Introduction to the Principles of Morals and Legislation*. He described the relation between morals and legislation in characteristically geometrical terms: 'legislation has the same centre with morals, but it has not the same circumference.' And the correcting influence of laws should begin at the point where the prudent operations of self-interest end: at the point where self-interest alone might not prompt us to 'abtain from diminishing the happiness of others'.

1. Quoted by F. Allengry, op. cit., p. 716.

In this complex form, the conception became the main foundation of liberal-democratic theory, and everywhere it served the purposes of the democratic revolution. In Britain, in the hands of the Free-Trade movement and in the form of Cobdenism and Gladstonian liberalism, it was used to demolish the old restrictions on trade, business and economic life in general; in the hands of the penal and judicial reformers, it cut through the tangle of out-dated statutes and penalties and cumbersome legal procedures; in politics it carried with it logical implications of political equality and universal suffrage. In France it was used by the revolutionaries to justify the creation of a republic, to sweep away the legal and social inequalities of the *ancien régime,* and to attack every institution which could not be justified in terms of a free society of equal citizens. Throughout Europe it undermined regimes based on traditional notions of feudal privilege; for no harmony of interests was conceivable between privileged nobles who exacted feudal dues whilst evading royal taxation themselves, and their tenants who had to pay both feudal dues and royal taxes. The Rousseau vision of a community of free and equal citizens, self-governing because unhampered by authorities intermediate between them and the state, and with each citizen 'thinking only his own thoughts', was now reinforced by the notion of a society of individuals simultaneously promoting both their own interests and the common good. This reinforcement gave the Rousseau vision substance and feasibility. What the force of gravity did for the material universe revealed by Newton, Adam Smith's 'invisible hand' did for the social order envisaged by the democratic revolutionaries. It gave it not only cohesion but also coherence. It brought it more within the grasp of man.

It was in such a faith that early socialism was born. When Robert Owen in England planned his 'New Harmony' and looked to education to remould mankind into a completely new species of creature, he was drawing one set of inferences from the doctrine. When Charles Fourier in France depicted the future fantastic phase of Harmony, when lions would be replaced by anti-lions with all the qualities lacking in present lions, and the globe would be inhabited by totally different species of animal life, he was carrying the same idea to its extremest absurdities. His drastic criticisms of existing civilization, in which each person in economic life is at war with the mass, and commerce breeds a multitude of vices, are well known. Conflicts of individual interests derived from the competitive commercial system, in which producers profited most from supplying inferior goods to consumers. On this contention Fourier built up his plea for co-operative principles in social life and buttressed it by his theory of 'attractions'. The discovery of this theory, he claimed, entitled him to rank above Newton. God has so arranged our passions that they serve socially useful ends. The care of infants, otherwise repulsive, becomes attractive to a mother because she is endowed with 'a passionate attraction for this dirty work'. His projected phalanges were

self-contained co-operative associations of workers, the units on which the era of Harmony would be based. When Proudhon, a possibly even greater influence on socialist thought than Fourier, propounded his theory of *mutualisme,* he placed himself in the same line of descent. His *système mutualiste* is a society which holds together its members by assuring 'service for service', and is in essence a voluntary, anarchistic version of co-operation.

To indicate the long-term revolutionary repercussions of the concept, it is necessary only to mention the names of Mazzini and of Woodrow Wilson. Mazzini, the champion of Italian unification through liberalism, believed in a sort of division of labour among nations. Each nation had special aptitudes, peculiar to itself, which fitted it to make a unique contribution to the welfare and progress of humanity. To contribute most to mankind and to international harmony, each nation had therefore to be true only to itself; and nationalism was automatically compatible with internationalism and indeed essential to it. Similarly, in 1919 President Woodrow Wilson, and many other liberal-democratic makers of the peace settlement, saw national self-determination as the key to world peace. Liberal-democratic revolutionary movements merged into nationalist revolutionary movements; and together they transformed the nature of European states and governments during the nineteenth century.

ROMANTICISM AND BIOLOGY

Although in these ways the revolutionary consequences of the rationalist movement carried forward far into the nineteenth century, during its first half there set in a powerful reaction against rationalism. This reaction gathered strength from a great diversity of other forces, and ended by completely recasting the mould of social and political thought.

In the first place, liberal-democratic rationalism had spent much of its original force, and was profoundly discredited by the excesses of the Reign of Terror and by the despotism of Napoleon to which the revolution had led. The defeat of Napoleon in 1815 brought a restoration of monarchs and a revival of traditionalism. Meanwhile, too, the romantic movement in thought and literature was a further protest against the aridities and inadequacies of scientific rationalism. Man was not, after all, a creature merely of reason but also of feeling and emotion; he had less sense and more sensibility than the enthusiastic rationalists has suggested. Society was not simply an aggregate of individuals each seeking his own self-interest: it was a nation, an organic, living community, with a spirit and a soul of its own which could be found in its literature and its art. No theory of self-interest, however enlightened, could sufficiently explain the heart of a nation which patriots felt pulsating within them and calling for sacrifice and love.

But if for these reasons faith in rationalism waned, what was to take its place? The answer came from a variety of sources. It came, in part, from German philosophy, whether Kantian or Hegelian, which emphasized the moral sense in man and found the basis of the state less in interests than in will and moral purpose. Hegelian categories tended to be collectives—nationality, folk traditions, the state—rather than the individual reason. Human societies, and the institutions they adopted, had their roots deep in the past, and had evolved by adaptation to changing social needs. As the Irishman, Edmund Burke, had reminded Europe, societies and states could not be suddenly uprooted and refashioned into new shapes, like mere machines. They should be treated with reverence, tenderly, as the flower of past wisdom.

But the answer came in part, too, from the natural sciences, and especially from the impressive contemporary developments in biology. Without the addition of this scientific influence to that Germanic philosophy, it seems likely that the political thought of the period would have been predominantly Burkian and conservative. It was the impact of scientific ideas and of scientific progress which again played a crucial part in the mediation between the general trends of philosophy and culture, and the genesis of new revolutionary movements. As Maxime Leroy remarks:

> The ideological trends and the social facts of this very disturbed period can be understood only in relation to one another and above all in relation to the trends in literature and science.[1]

Natural science contributed to the general thought of the time two ideas which were to have far-reaching importance for social and political theory. One was that progress might come not, as mathematicians like Descartes and Condorcet had taught, through deductions from certain accepted truths by a process of geometrical logic, but by the patient collection and classification of observed and tested facts and by reflection upon the meaning of the pattern thus revealed. It was by collecting and classifying specimens of animals and plants discovered all over the world that, in the eighteenth century, the Swede Linnaeus and the Frenchman Buffon had earned their immense reputation. The reverence for what exists, examined and described for its own sake, was in many ways an antidote to the Germanic concern with what ought to be. In the theories of Lamarck the botanical and zoological knowledge thus accumulated was used to support the notion that throughout a vast period of time a slow process of evolution had changed one form of creature into another in an ascending series, and that animal organisms had become more specialized as higher levels in the series were reached. This concept, that the earth has had a continuous history and that

1. Maxime Leroy, *Histoire des idées sociales en France*, Paris, 1954, vol. III, p. 129.

living organisms have some evolutionary interconnexion, was the second great contribution of contemporary science to the thought of the early nineteenth century. It was in accord with the growing emphasis on an historical, evolutionary and organic view of man and society as closely as Cartesian and Newtonian mathematics had matched the ethics and politics of the eighteenth century.

Both these conceptions had obvious possible applications to political thought; but whereas the reverence for existing facts and the concept of gradual evolution tended to have conservative implications, the search for a new understanding of life through systematic observation and induction had, in the circumstances of the time, new revolutionary consequences. To revive interest in the detailed study of immediate social conditions and problems in the circumstances of the early phases of the industrial revolution was to encourage socialism and eventually Marxism. It is in this connexion that the most influential writers of the romantic movement effected one of those crucial interconnexions that Leroy indicated. Balzac, in the preface to his great *Comédie humaine,* declared himself the disciple of the naturalist Geoffroy Saint-Hilaire. Society, he held, made of man as many different species as exist in zoology, and he set out in his novels to reveal the panorama of human life as the zoologist studies animal life and habits. It was to Balzac that Friedrich Engels paid the remarkable tribute: 'I have learned more from Balzac than from all the works of the historians, economists and professional statisticians of the period put together.'

As in earlier times, eminent scientists themselves joined republican and revolutionary movements, and directly transferred the outlook of science into the spirit of politics. Georges Cuvier supported the first Saint-Simonian journal, *L'Industrie,* in 1817. François Raspail, one of the most eminent leaders of the more extreme republican movement in France, began life as a chemist. He attained enough distinction for Geoffroy Saint-Hilaire to write to him in 1833 as a master, and he has since been acclaimed one of the founders of microbiology and a precursor of Louis Pasteur. He regarded science and medicine as the supreme remedies for the ills of the working classes; and he insisted on universal suffrage and republican institutions as the pre-requisites for the proper application of these remedies. To the same republican movement François Arago lent his support. He was among the more eminent of the physicists and astronomers of mid-nineteenth-century France, and became Minister of Marine in the provisional government of 1848. The Second Republic of that year was the common meeting-ground for the leaders of the romantic movement such as Lamartine and Hugo and the leaders of science such as Raspail and Arago.

Meanwhile, too, the practical consequence of applying medical and biological science to society was a momentous lengthening of human life which itself forced a revolution in social thinking. By 1850 there were nearly

80 million more Europeans than there had been in 1800, an increase of nearly 40 per cent. The most important single reason for this remarkable fact was that the new medical science gave each individual from birth a better chance of survival. Combined with the spread of industrial technology, this revolution in science 'filled the towns instead of the cemeteries'. Urbanism forced people to think more urgently and strenuously about social problems. It was to inaugurate what the followers of Saint-Simon were the first to recognize as an age of the masses. Its natural consequence was not only a new focus of thought but also a new cult of youth. This cult of youth took the literary and artistic forms of the romantic movement, and the political forms of the nationalistic 'Young Europe' movements of the eighteen-thirties. The population of Europe at that period was younger and felt younger. The movements which flourished were those which most appealed to youth; and the young Lord Byron, dying whilst supporting the cause of Greek independence, symbolized the spirit of the times which earnest German students of the *Zeitgeist* were beginning to regard as all-important in politics. This whole change in outlook and spirit was closely connected with the development of science.

But by the middle of the century this phase was passing. By then utopian socialism had spent its force, liberal nationalism had suffered setbacks in 1848, and revolutionary romanticism had enjoyed short-lived triumphs. Rationalism reasserted itself, though in new forms, in the movement of positivism. It, too, was powerfully conditioned by the ideas of the mathematical and natural sciences.

THE PROGRESS OF POSITIVISM

Revolutionary rationalism seemed to have failed by 1815, revolutionary romanticism by 1850. In literature and art romanticism gave way to naturalism and realism. In part this was a reaction against the excesses and exaggerations of romanticism. By emphasizing 'natural truth', the historical reality out of which the present had emerged, romanticism encouraged greater attention to concrete detail and verifiable fact. The heroic, lyrical, imaginative elements in romanticism lost their force; the naturalistic and realistic elements remained. As Emile Bourgeois has put it, describing the reaction against romanticism:

> Acting under the influence of the scientific spirit, of that love of clearness and precision, that quest for the definite fact and the document, which was the peculiar characteristic of the later part of the century, a new literature gradually took form and shape, a positive literature which adopted as its guiding principle the faithful reproduction of the life around it, without any modifications save those which the laws of art necessarily impose upon the artist.[1]

1. Emile Bourgeois in *Cambridge Modern History*, vol. xi, p. 509.

The spirit of revolutionary and nationalist movements underwent a parallel transformation in the quarter century after 1850. The Italian *risorgimento* fell under the leadership of the realist Cavour rather than of the romantic Mazzini; Bismarck set about the unification of Germany by 'blood and iron'. In France, during the Second Empire, the republican opposition fell to the leadership of a younger generation of men, in particular Gambetta, who imbibed the positivist philosophy taught by Auguste Comte and inherited from Condorcet and Saint-Simon. Confident that human reason, scientifically applied, could remove all mysteries and remedy all social ills, they also had faith in progress. Man could so mould his environment and his social institutions that both spiritual and material improvement could be predicted as the future of mankind. But first there must be established universal male suffrage and representative institutions: a positivist republic, defying the reactionary powers of clericalism and monarchism and firmly based on the alliance of democracy and science, particularly in education. In the Paris *salons* frequented by these young republican leaders, especially in that of Madame Juliette Adam, the deism of Hugo gave place to the positivism of Comte. When the defeat of the Second Empire in 1870 opened the doors to the Third Republic, it was Gambetta and his disciples who first inherited power. The old romantic revolutionary tradition, represented by veteran Jacobin conspirators like Auguste Blanqui, Félix Pyat and Charles Delescluze, was destroyed in the overthrow of the Paris Commune of 1871. When by 1875 the liberal Thiers and the conservative Duc de Broglie had safely established the Third Republic, it was the younger republicans who increasingly took it over. And the first purposes to which they put their new power were characteristically positivist purposes. The engineer Charles de Freycinet, as Minister of Public Works, put through a 10-year plan for expanding the transport system of the country; Jules Ferry established the system of state primary schools which taught the secular principles of positivism and civic duty and fought to free education from clerical control. Under the Third Republic the new educational laws were often administered by scientists—men like the physiologist Paul Bert, the great chemist Marcelin Berthelot, and the mathematician Paul Painlevé.

Positivism, as Professor Hayek has argued, can in many respects serve the cause of authority and even reaction. (Comte himself visualized scientists as a new priestcraft and science as a new religion.) Its impersonal qualities can have a dehumanizing effect on political theory. But positivism as practised by the Third French Republic was undoubtedly a republican and revolutionary movement. It aimed at nothing less than the transformation of French life and outlook, through secular education and extensive public works. By replacing romantic Jacobinism as the mainspring of French republicanism, it reverted to the rationalism of the time of Condorcet and tapped anew one of the original sources of the French revolutionary movement. And

in its genesis and growth as a political movement it was dominated no less thoroughly than its predecessors by the ideas of mathematics and science.

The impact of the relatively new sciences of philology and ethnology on republican thought can be traced in the remarkable work written by Ernest Renan in 1848, but published only in 1890: *L'avenir de la science*. Written at the magic moment of 1848, when Renan was only 25, it expresses all the doubts and hopes of his time and age. But it also expresses his faith that eventually, through the development of such social studies as philology and epigraphy, comparative religion and history itself, progress will come and civilization will advance. The patient accumulation even of apparently insignificant details of knowledge must result in man's better understanding of himself.

> Cuvier dissecting snails would have brought a smile to the thoughtless who do not understand the methods of science. The chemist handling his apparatus looks as if he were a manual labourer; and yet he is performing the most liberal of all tasks—research into what is. Is the philologist working with words and syllables to be paid any less honour than the chemist working in his laboratory?[1]

In his preface of 1890 he reaffirmed his faith in this approach; and it was in such a spirit that Gabriel Tarde, Emile Durkheim and Gustave Le Bon laid the foundations of modern sociology. By that time, however, Darwinism had introduced a powerful new force into the study of society and politics of which the consequences lie beyond the scope of this article.

The study and writing of history in France was particularly transformed by realism and positivism. Having become 'romantic' in the hands of Lamartine and Michelet, it became 'realistic' with Thiers and Guizot, 'scientific' with Taine and Renan. It came to rely more and more on original documents, became more precise and exacting in its methods of assessing evidence, more richly endowed by materials which were becoming available from philology and epigraphy, Egyptology and archaeology. Whereas romantic history had emphasized ideas and personalities, positivist history emphasized material conditions and impersonal forces. In Germany this tendency to treat history as a science was especially strong, and reached its apogee in Leopold von Ranke. German *Historismus*, in origins a revolt against the universalism of the Enlightenment, emphasized the particular, and above all the nation, in man's heritage from the past. In the circumstances of nineteenth-century Germany this scientific conception of history had revolutionary consequences. It has been claimed that 'the conception underlying the revived German Reich of 1871, and the Third Reich of 1933, would scarcely have been possible without the work of the German historical school'.[2] And the influence of the German school of historians upon the

1. Ernest Renan, *L'avenir de la science*, Paris, ed. of 1905, pp. 211-13. See also the study of this book by Maxime Leroy, op. cit., chap. X.
2. *Nationalism: A Report by a Study Group of Members of the Royal Institute of International Affairs*, London, 1939, p. 42.

writing of history in most other countries, including Great Britain and the United States, was destined to be immense. Soon no political movement—least of all a revolutionary movement—could hope to get far without producing the most erudite historical credentials. Karl Marx, like Hegel and Comte, felt it necessary to rest his whole philosophy on a 'scientific' interpretation of history. 'Scientific' history alone was capable of giving a political theory plausibility and reality; and men could choose to go only where the course of history, thus interpreted, showed that they were going anyhow.

THE SCIENCE OF REVOLUTION

If the study of history could be a science, why could not the study of revolution? And if the study of revolution, why not the making of it? The culmination of the century-long process by which scientific thought had influenced revolutionary movements was the attempt of Marx and Engels to reduce revolution itself to a science. Marxism was the synthesis of a century's revolutionary ideas. In an age when most Europeans had boundless faith in progress, it was natural for forward-looking men to turn increasingly to science as the basis for hope. Both faith and hope could be maximized if progress could be shown to be inevitable and if revolution could be reduced to a science. Because Marxism could claim to do both, it was to become the most dynamic revolutionary movement of the twentieth century. With the genesis of modern communism this investigation can most fittingly end.

It was not new for revolutionaries to study revolutionary technique. The romantic age had bred its professional revolutionaries—men who, like Blanqui or Delescluze, devoted their lives to the cause of conspiracy and insurrection in the tradition of the secret societies. They had come to lavish attention upon the techniques of revolt, and had evolved elaborate devices for cheating the police and planning a popular rising. But they spent a large proportion of their lives in gaols, and their adventures were usually complete failures. The Paris Commune of 1871 was the death-blow to this romantic tradition of the barricades. Its passing was heralded by the new 'science of revolution' propounded by Marx and Engels. Condemning ideas like Blanqui's as impracticable, and socialists like Saint-Simon and Fourier as utopian, Marx and Engels claimed to have discovered a scientific basis on which the communist revolution would proceed. The care with which Engels, in *Anti-Dühring,* sifts from earlier socialism all that he regards as of value to Marxism, and grafts it on to the more recent conceptions of science shows clearly enough the purpose he had in mind:

> The conception was prevalent among the French of the eighteenth century, as well as with Hegel, of Nature as a whole, moving in narrow circles and remaining immutable, with its eternal celestial bodies, as Newton taught, and unalterable species of organic

beings, as Linnaeus taught. In opposition to this conception, modern materialism embraces the more recent advances of natural science, according to which Nature also has its history in time, the celestial bodies, like the organic species which under favourable circumstances people them, coming into being and passing away, and the recurrent circles, in so far as they are in any way admissible, assuming infinitely vaster dimensions. . . . What still independently survives of all former philosophy is the science of thought and its laws—formal logic and dialectics. Everything else is merged in the positive science of Nature and history.[1]

The sciences which especially impressed Marx and Engels, besides the statistical study of economics, were anthropology which they regarded the American Lewis H. Morgan as having put on to a new basis, and biology which Darwinism had revolutionized. Engel's lengthy study of *The Origin of the Family, Private Property and the State* was but an account and an interpretation of Morgan's work. In his preface to the English edition of *The Communist Manifesto,* Engels described its principles as 'destined to do for history what Darwin's theory has done for biology'; five years earlier, in his speech at the graveside of Marx, he claimed that 'just as Darwin discovered the law of development of organic nature, so Marx discovered the law of development of human history'. He added that 'science was for Marx a historically dynamic, revolutionary force'. The affiliations between Marxism and Darwinism have been frequently and extensively discussed, but the debt of Marxism to the ideas linked with scientific thought in the whole of the previous democratic revolutionary movement has been hardly considered.

It is not a question of particular debts to particular writers. It is a matter of appropriating and synthesizing most of the main ideas which the revolutionary movement shared in common with scientific thought. Thus the expectation of unanimity is projected into the future classless society which will succeed the proletarian revolution; and so, too, is the idea of a natural harmony of interests between individual and society. From the rationalism of the enlightenment and the ideals of the French Revolution came also the main ethical ideas of Marxism. It did not try to show why it should be regarded as bad for man to be exploited by man, for proletarian to be at the mercy of bourgeois in a capitalist society; nor why, conversely, it would be good and desirable for men to be more free and less poor. Marx took over tacitly and intact the rationalist and humanitarian scale of values on which such judgments rested. They came directly from the liberal and social democratic revolutionary movement; and there are no ethical judgments to be found in Marx which are not to be found also in his predecessors.

For these reasons, there is a surprising amount of common ground between Marx and Bentham—whether in the materialistic basis of their philosophies and the common goal of maximizing and generalizing human happiness; or in their insistence upon conflicts of interest as the basis of society; or in their

1. Frederick Engels, *Herr Eugen Dühring's Revolution in Science (Anti-Dühring),* English translation, London, 1934, p. 31.

common distrust of politics and the State, for does not Marx look forward to the day when 'the public power will lose its political character', and ultimately the State will wither away because it no longer has anything to do? Even in their reliance, nonetheless, upon the use of political power to create the conditions necessary for its own disappearance, they have a marked similarity of ideas. And in their universalism they are equally unlike the romantic and more nationalistic thinkers who in point of time fell between them. Their common ground derives not only from the fact that both belonged to the same broad tide of revolutionary thinking; but also that each was subject to an impact of scientific thought, positivist in character and critical in method. Perhaps the greatest difference lies in the theory of historical and dialectical materialism which Marx elaborated.

The positivist idea of history, the notion of a long-range historical process which becomes intelligible once its schematic principles have been revealed, is to be found in Hegel, in Saint-Simon, in Comte, and in others. But in his elaboration of this idea in terms of economic conditions and changes Marx was original. He linked to his materialist interpretation of history the notion of an irresistible and inevitable dialectical process. It was akin to the normal nineteenth-century assumptions of western civilization, in that Marx's doctrine of progress presupposed, like them, a future of peace and plenty. But unlike them, it presupposed also revolutionary moments, when the proletariat, as the predestined medium of revolution, would wrest power from the bourgeoisie. His whole positivist and 'scientific' analysis of social and political conditions focussed upon explanation of such moments. They would inevitably come, and their eventual outcome was beyond doubt. But if the proletariat, led by its communist vanguard, knows precisely how to act and to react at such moments, the process of revolution can be eased and made more painless. In short, there is a 'science of revolution'. It replaces the former 'art of revolution' which had proved ineffective in the hands of Blanquists and utopians. From the detailed analysis of economic statistics and from theories built upon such analysis, the scientific revolutionary is able to report upon the latest stage in the class war; and upon the balance of forces so revealed the outcome of revolutionary acts must finally depend.

In each phase of European thought and culture between the mid-eighteenth and mid-nineteenth centuries, there were close affinities and interplay between the general philosophical, literary and scientific trends of thought and social and political movements. Such interplay was assured by continuance of the belief that all products of human intelligence would ultimately form one corpus of knowledge and thought. In the mediations between one great phase of thought and its successor, the contribution of scientific ideas was often of crucial importance. In an era when the truths revealed by science were held in growing reverence and produced the most impressive practical

results, political doctrines and ideals were constantly compelled to demonstrate their similar certainty and their equally positive qualities. The forces seeking political and social change tend always to establish strong affinities with the ideas which are most novel or which are changing most rapidly. And because, in the years between the French Revolution and the formulation of Marxism, the ideas which were changing most rapidly were scientific ideas, science must be considered as one of the strong and constant influences on the birth and growth of modern revolutionary movements.

THE POSSIBILITIES OF SOILLESS CULTIVATION

by

J. W. E. H. SHOLTO DOUGLAS

The author, who is an agronomist of the U.K. Ministry of Food, has been responsible since 1946 for the development of soilless cultivation at the West Bengal Agricultural Institute and the experimental stations at Darjeeling and Calcutta, and is the originator of the Bengal methods of hydroponics.

Ever since the publication in 1798 of Malthus' *Essay on Population,* there have been periodical warnings that in time mankind would face starvation, owing to the number of the world's inhabitants outgrowing the available food supplies. Fortunately, this grim prediction has not yet come to pass. True, the possibility still remains, but the immense advances made in agricultural science, and the consequent increased production, seem to have staved off disaster—at any rate for the time being. Nevertheless, nothing would be more ill-advised than an attitude of complacency. Although food surpluses may arise in some areas, there can be actual famine in others. No less than three-quarters of the world's population is inadequately nourished. Problems of distribution are still unsolved. An unexpected failure of harvests in one country is capable of creating a dearth in several others. Currency rules and tariff barriers frequently prohibit the movement of stocks from areas of over-production to lands where food is urgently needed. In short, the general food problem is as far from being solved as ever, and it is likely to remain so until new methods of producing food in the areas where it is most needed are introduced on a large scale.

One of the most promising of the new methods is soilless cultivation. It is not generally realized that a way of cultivating food crops without using any soil at all has been evolved. Also known as hydroponics—a word derived from the Greek, meaning 'water-working', as opposed to geoponics or agriculture, meaning 'care of the earth'—this growing of plants without soil has now become a practical proposition. Many successful installations are flourishing in various parts of the world, under all manner of climatic conditions. By divorcing food production from the soil, hydroponics enables countries lacking fertile farmland to grow all the crops they need to nourish their people. It is no exaggeration to say that the introduction of soilless cultivation on a large scale can provide the solution to the problem of local hunger. Excellent crops can be grown without soil, at low cost and with a minimum of trouble, in places where conventional methods of agriculture are impos-

sible. By bringing cheap and nourishing foodstuffs within the reach of all, hydroponics offers something of real value to humanity.

THE ORIGINS OF HYDROPONICS

Hydroponics is the art and science of growing plants without soil by feeding them on chemical solutions. Crops can be raised in the absence of organic matter simply by giving them in artificial form the nutrients which they usually draw from the earth through their roots. The basic principles of soilless culture are not new. In fact, for nearly a century workers have been producing plants for physiological experiments in their laboratories by the use of similar methods, but until a few years ago nobody had ever thought of adapting or applying such ideas to practical or commercial food production. Indeed, the sole object of water culture experiments was to enable the farmer to make better use of his soil. Then, suddenly, amazing results were obtained by Californian researchers who managed to raise crops without any soil at all, by growing them out of doors in nutrient solutions or inert media moistened by cultural infusion. This was the beginning of a new and successful method of crop growing.

The study of crop nutrition began thousands of years ago, long before the time of Aristotle. Ancient history recounts that various experiments were undertaken by Theophrastus (372-287 B.C.), while several writings of Dioscorides on botany and its allied subjects, dating from the first century A.D., are still in existence. The earliest recorded scientific approach to the question, however, was that of Woodward (1699),[1] who worked in England with water cultures to try to determine whether it was the water or the solid particles of soil that nourished the plants. At the time, it was commonly believed that 'for nourishment of vegetables the water is almost all in all'. Van Helmont had grown a willow for five years in an earthen vessel containing 200 pounds of soil to which nothing had been added except rain water or distilled water, and had produced a tree weighing 169 pounds at an expenditure of only 2 ounces of soil. But Woodward has recorded his disagreement with the current ideas. He wrote that 'earth and not water is the matter that constitutes vegetables'. His conclusion was based upon experiments in which he grew spearmint in glasses containing water from various sources, methodically recording the initial and final weights of the plants and the total amount of the liquid consumed. He observed that the addition of an ounce and a half of garden soil to the water increased the 'terrestial matter' and consequently the growth of the plants.

Handicapped as they were by lack of equipment, investigators of those

1. J. Woodward, 'Thoughts and Experiments on Vegetation', *Philos. Trans. Royal Soc.*, London, 1699, *21*, 382-98.

times could make little progress. But modern chemistry, built up during the seventeenth and eighteenth centuries, subsequently revolutionized scientific research. The experiments of Sir Humphrey Davy, inventor of the safety-lamp, had evolved a method of effecting chemical decomposition by means of an electric current. Several of the elements which go to make up matter were brought to light, and it was now possible for chemists to split up a compound into its constituent parts. By 1842, a list of nine elements believed to be essential to plant growth had been made out, and the discoveries of the German workers, Sachs[1] and Knop, in the years 1859-65, resulted in the development of a technique of soilless culture in the laboratory. The addition of a chemical to water was found to produce a nutrient solution which would support plant life, so that by 1920 the laboratory preparation of water cultures had been standardized and the methods of conducting trials were well established.

Until 1928, however, the phrase 'crops without soil' was virtually unknown. The value of the discoveries had not been realized. In that year, Robbins, working at the New Jersey Experiment Station, suggested[2] that sand culture had possibilities for research and commercial work in horticulture. This was followed by a similar announcement by Biekart and Connors,[3] of the same institution. At Ohio State University, Laurie issued an account of the trials carried out there with washed sand in greenhouse culture.[4] A further step was taken in 1929 when Professor W. F. Gericke, of the University of California,[5] succeeded in growing tomato vines 25 feet in height. Even the most incredulous critics were impressed. A new factor had suddenly appeared and was making itself felt in the world of practical and scientific agriculture. Such a novel technique was bound to attract great attention. The American press hailed it as one of the most colossal inventions of the century, reporting with magnificent abandon that farmlands had become relics of the past. Many extravagant and irresponsible claims were made for the new science, which could not at that time be justified.

DEVELOPMENT OF TECHNIQUES

Although hydroponics had broken laboratory bounds and in one stride entered the world of practical horticulture, it was still an involved and complicated technique. Because of this, and the fact that the different functions

1. Julius von Sachs, *Lectures on the Physiology of Plants*, Clarendon Press, London, 1887.
2. W. R. Robbins, 'The Possibilities of Sand Culture for Research and Commercial Work in Horticulture', *Proc. Amer. Soc. Hortic. Sci.*, 1928, *25*, 368-70.
3. H. M. Biekart and C. H. Connors, 'The Greenhouse Culture of Carnations in Sand', *N.J. Agr. Exp. Sta. Bull.*, 588, 1935.
4. Alex. Laurie, 'The Use of Washed Sand as a Substitute for Soil in Greenhouse Culture', *Proc. Amer. Soc. Hortic. Sci.*, 1931, 28, 427-31.
5. W. F. Gericke, *The Complete Guide to Soilless Gardening*, New York, Prentice Hall, 1940.

of the various parts of the necessary apparatus were imperfectly understood, early sensational publicity threatened to destroy its future. Unscrupulous adventurers attempted to 'cash in' on the discovery by selling useless equipment at fantastic prices to the ignorant or the credulous. Fortunately, experienced research workers and scientific institutions continued to give hydroponics considerable thought and attention.

Gericke had grown his first plants in waterproof troughs or benches of any suitable material. A wire grid fitted closely over the top of each tank which contained the nutrient liquid. The grid served as a support for the growing plants, whose roots descended through the mesh into the solution below. A covering of wood wool (excelsior), peat or shavings, or some other inert material served to exclude light from the solution, besides giving additional support and protection to the crop. Aeration of the roots was ensured in this system by adjusting the level of the nutrient so as to leave an air space between its surface and the base of the wire grid.

Some changes had to be made in the practical operation of these Californian methods, so as to adapt soilless culture to the requirements of the Middle West and the eastern seaboard states of America. In the original New Jersey technique, the required nutrients were supplied to the crops by mixing the necessary chemicals in an elevated tank of water from which the solution flowed by gravity to impregnate the bench of sand in which the plants grew. Later this was abandoned in favour of waterproof troughs into which the liquid nutrient was forced several times a day by an electrically driven centrifugal pump. Other variations on these themes, all using sand as the anchor for the crops' roots, soon followed. There was the surface watering system, in which the requisite nutrients and water were supplied in solution from a hosepipe to the surface of the medium; and there was also the automatic dilution surface watering technique—favoured by Imperial Chemical Industries Ltd., in the Jealott's Hill Research Station at Bracknell, Berkshire, England[1]—where a means of automatically diluting a concentrated solution, and of applying it through a system of sprays to the sand bed was evolved.

In addition to these methods, some institutions experimented with the drip culture and the dry application systems, both of which gave good results. In the former, diluted nutrient solution contained in an upper tank is allowed to drip continuously, through a feed line, on to a bed of sand in which plants are grown. The solution percolates through the medium, is collected in a sump, and pumped back to the reservoir at intervals. The dry application system entails the sprinkling of dry mixed chemicals periodically over the beds, followed by immediate watering in of the salts. From the use of sand in the troughs, research workers soon moved on to the employment of other

1. Imperial Chemical Industries Ltd., Jealott's Hill Research Station, Bracknell, Berkshire, *The Culture of Plants in Sand and in Aggregate*, Bulletin no. 2 (revised)), March 1947.

growing mediums. This led to the development of aggregate culture, now popular in Europe and in some damp tropical areas. This system demands a water-tight trough filled with gravel or some other aggregate coarser than sand, which is periodically flooded with dilute solution from below, and then allowed to drain. It has been very successful where material and labour are available to build the beds and instal the apparatus. Frequently known as the sub-irrigation technique, from the way in which the solution is introduced to the troughs, aggregate cultivation also makes use of the device known as a flume. This contrivance consists of a curved artificial channel down which the liquid nutrients are directed so that each trough may receive a correct proportion as the solution passes it. Flumes have been employed with great advantage by growers in Florida.

Despite the excellent reports of its efficacy as a means of crop production, hydroponics had not spread among the general public. This was mainly due to the elaborate apparatus and equipment required for the operation of the methods advocated up to quite recently.

The world war of 1939-45 resulted in a spread of hydroponic cultivation to many different areas, and a general realization of the immense possibilities of soilless growth began to dawn upon agronomists everywhere. In 1946 research studies were commenced at the Government of Bengal's experimental station at Kalimpong, in India, with the object of introducing a simple and practicable technique, suitable for popular use. In 1948 it was possible to announce the development of the Bengal system of hydroponics,[1] which incorporated substantial modifications of all previous practice. The plants could be grown in troughs built from any suitable material, and filled with a mixture of five parts of rock chips, leached cinders, gravel, or broken bricks, of five-eighths to one-quarter inch grade, and two parts of sand. Substitutes, such as peat, could also be employed. The nutrients are applied dry, at regular intervals, in stipulated ratios to the area of the bed surface, either as fertilizer grade chemicals, or as synthetic resins. Packeted powdered compounds or tablets can be utilized. After application, the salts have to be watered in with a light spray of water, if there is no rain. No elaborate equipment is required for a hydroponicum of this type, and extensive use may be made of local indigenous materials. Simple rules must be followed by the grower, but if these are carefully adhered to, anyone can use the method without special knowledge or training. The Bengal system of hydroponics, adapted and modified for different climatic zones and conditions, is today rapidly spreading throughout the world and becoming very popular on account of its comparative simplicity, economy, and ease of installation.

Among institutions which have contributed to the establishment of the soilless cultivation of plants as a practical proposition are the Universities of

1. *Hydroponics (Soilless Cultivation)*, Bulletin no. 1, December 1947 (published 1948), Hydroponic Research Centre, Government of West Bengal Experimental Farm, Kalimpong, Darjeeling, India.

Illinois, Ohio, Purdue, and California, in the United States; the University of Reading in Great Britain; Canada's Central Experimental Farm at Ottawa; and Imperial Chemical Industries Ltd. Other pioneers of hydroponics were the Boyce Thompson Institute for Plant Research, New York; the New Jersey Agriculture Experiment Station; the Alabama Polytechnic Institute; and the Experimental and Research Station, Cheshunt, Herts., England. In Asia, the lead was taken by the Bengal Agricultural Department, and by the successor government of West Bengal in India, which sponsored the development work and research initiated at the Agricultural Institute and the experimental farm at Kalimpong. Consequent upon this pioneer effort, Hydroponic Research in India has encouraged the spread of soilless culture throughout the country, and is now attempting to develop the simple and practicable Bengal methods in other areas. An information centre has been opened at Post Box 31, Bombay, India, where books[1] and advice are available. It is worthy of note that the British Ministry of Agriculture and Fisheries gave financial aid at the beginning of the work.

YIELDS AND QUALITY

Today hydroponics is an established branch of agronomical science. Progress has been rapid, and the results obtained during the past five years in various countries, including the work conducted in Bengal, have proved it to be thoroughly practical and to have some very definite advantages over normal soil culture. The two chief merits of hydroponics are, first, much higher crop yields, and secondly, the fact that it can be used in places where ordinary agriculture or gardening is impossible. Not only is it a profitable undertaking, but it enables people living in crowded cities to grow fresh vegetables in window boxes or on house roofs. Town residents and workers in industrial settlements often have verandahs, backyards or pavements of which they can generally make little use. By means of hydroponics all such odd corners can be made to yield a regular and abundant supply of greenstuff. Other possibilities are factory roofs or disused roads. Not only town dwellers, but also country residents, can profit from soilless culture. Deserts, rocky and stony ground in mountainous districts, or barren and sterile areas can be made productive at relatively low cost. It is no exaggeration to say that hydroponics may mean as much to the landless worker as the abolition of slavery.

Apart from the advantages already mentioned, there are others, in particular quicker growth combined with relative freedom from soil diseases, and very consistent crops, the quality of the produce being excellent. There is

1. J. W. E. H. Sholto Douglas, *Hydroponics: The Bengal System*, illustrated, Oxford University Press, 1951.

also a considerable reduction in growing area, weeds are practically non-existent, while standard methods and automatic operation mean less labour, less cost, and no hard manual work. As many plants can be raised out of season, better control of crops naturally results; moreover, there is no dirt and no smell. Waterlogging never occurs, owing to good drainage. Nor does the use of hydroponics alter the taste of a crop in any way. In fact, the piquant savour of soilless-cultured produce cannot be found anywhere else in agriculture. There is no other distinction between a chemically grown plant and a naturally raised one in point of flavour, nor have analyses shown any difference in vitamin content. Special crops of unique dietary value—such as tomatoes with a high calcium content for babies—can be grown at will.

Table 1 shows some yields obtained by hydroponics as compared with those obtained by conventional methods in soil.

TABLE I.

Crop	*Best agricultural yields*	*Hydroponic yields*
Tomato	12 lb per plant (U.S.A.)	27.4 lb per plant (var. Sutton's Majestic, University of California)
	11 lb per plant (U.K.)	16.4 lb per plant (var. Stonor's M.P., Jealott's Hill Research Station, England)
	10 lb per plant (India)	22.5 lb per plant (var. Best of All, Hydroponic Research, India)
	Average per acre: 5-50 tons	Average per acre: 150-200 tons
Rice	900 lb per acre (India)	5,000 lb per acre (broadcast)
	3,000 lb per acre (Italy, Japan)	9,000 lb per acre (transplanted, West Bengal)
Potatoes	30 tons per acre (California)	65 tons per acre (Dr W. F. Gericke, California)
	12-15 tons per acre (U.K.)	70 tons per acre (Agricultural
	9 tons per acre (Bengal)	Station, Kalimpong, India)
Maize	2,000 lb of grain per acre (North Bengal)	6,000 lb of grain per acre (Bengal)
Lettuce	9,000 lb per acre (North Bengal)	21,000 lb per acre (Hydroponic Research, India)
Beetroot	9,000 lb per acre (North Bengal; Calcutta Exptl., Sectors)	20,000 lb per acre (Calcutta Exptl. Sectors)
French beans	210 lb from 1,000 sq. ft trough (var. Dwarf, Canadian Wonder, North Bengal)	588 lb from 1,000 sq. ft trough (var. Dwarf, Canadian Wonder, Hydroponic Research, India)
Cauliflowers	10,000-15,000 lb per acre (Bengal)	32,000 lb per acre (Bengal)
Lady's fingers	5,000-8,000 lb per acre (Bengal)	19,000 lb per acre (Bengal)

Other crops successfully grown in hydroponics include: peas, broad beans, onions, cabbage, oats, soyabeans, cucumber, brinjal or egg-plants, squash or vegetable marrow, wheat, turnip, carrot, flax, great millet, millet, black beans or dal, gram or chickpea, radish, scarlet runner beans, chillies or

peppers, sponge gourd, bitter gourd, snake gourd, pumpkin, chrysanthemum pyrethrum, sugar-cane.

COMMERCIAL ACHIEVEMENTS—

The real development of soilless cultivation began when, having broken laboratory bounds, it was taken up by government departments and commercial organizations. The first great achievement came when Pan-American Airways decided to establish a hydroponicum on distant and barren Wake Island in the middle of the Pacific Ocean, in order to provide the passengers and crews of the airliners with regular supplies of fresh vegetables. In 1945 the British Air Ministry took steps to commence soilless culture at the desert air base of Habbaniyah in Iraq, and at the arid island of Bahrein in the Persian Gulf, where there are important oilfields. In the case of Habbaniyah, an important link in Allied communications during the war, all vegetables had had to be brought by air from Palestine to feed the troops stationed there. The U.S. Army now has a special Hydroponics Branch. Some of the most successful installations have been those at military bases, notably in British Guiana, Iwojima, and Ascension Island. American Headquarters in Japan started with 16 five-acre units devoted to vegetable growing, while various oil companies in the West Indies operating on barren or isolated islands, especially off the Venezuelan coast at Aruba and Curacao, have found soilless culture invaluable for ensuring that their employees get a regular ration of greenstuff.[1] In the continental United States itself there are extensive commercial hydroponicums, especially in Illinois, Ohio, California, Indiana, and Florida. New Yorkers are taking increasingly to skyscraper gardening. Russia, France, Canada, South Africa and Germany are among other countries where hydroponics has received attention. The English carnation growing industry has partly switched over from soil to soilless methods.[2] In fact, experiments have shown that gravel grown plants averaged 10.5 flowers against 8.9 for soil produced ones, costs being 28 per cent less in hydroponics.[3]

It is also of interest to note that a primitive form of hydroponics has been carried on in Kashmir for centuries. Visitors to that state will have observed light frameworks of branches, covered with rotten vegetation, floating on the numerous lakes. Excellent crops are raised by the local peasantry from these rafts which provide both water and nutrients to the growing plants. A commercial corporation has been formed to establish soilless cultivation in the

1. C. Ellis and M. W. Swaney, *Soilless Growth of Plants* (2nd Ed., revised and enlarged by T. Eastwood), New York, Reinhold Pub. Corpn., 1947.
2. British Carnation Society, *Soilless Cultivation of Carnations*, London, 1946.
3. A. Mussenbrock and G. Beach, 'Cost Comparisons—Soil and Gravel-grown Carnations', *Am. Soc., Hortic., Sci. Jour.*, 1947, p. 623.

Bahama Islands, while the simplified Bengal methods are rapidly spreading in Southern Asia, the adjacent areas, and South and East Africa. Australia and New Zealand have also expressed great interest in these new techniques. In India, thousands of hydroponicums in the large cities are producing vegetables for the crowded population.

—AND SCOPE OF HYDROPONICS

In fact, soilless cultivation, conducted according to the new simplified methods, can make all the large cities of the globe, such as New York, London, Paris, Calcutta, Buenos Aires, Rome, and Tokyo, self-supporting in all vegetables, thus leaving the available fertile country farmlands free to concentrate on cereal production. Millions of tons of nourishing foodstuffs could be grown in hydroponicums. Not only could immense barren lands be made productive, but crops might also be raised in sterile and arid regions, such as the Sahara Desert, the wastes of Arabia or Central Asia, the 'bad-lands' of the Middle West of America, the rocky highlands of Japan, or the undeveloped territories of Australia, Canada, and Patagonia.

It is not claimed that hydroponics should replace agriculture, but it has been proved beyond doubt that waste land, rocks, even house-tops and back verandahs—anywhere that sufficient sunshine and water are available—can be made to bloom and bear at little cost in money and trouble. In colder lands, plastic domes may be placed over the beds, with artificial heating devices arranged to provide warmth during winter. Where water is scarce it will be better conserved by running the available supply into controlled hydroponic beds than by dissipating it recklessly over the earth, as is done in ordinary irrigation, and so losing over half in evaporation. Heavy inter-cropping and closer sowing than horticulture permits has raised some hydroponic yields phenomenally. Rotation of crops is unnecessary, and the townsman can have year-round home produce. Almost any discarded receptacle lying about the house can be used by the housewife to grow vegetables in quickly.

Soilless cultivation has been listed by an American Government investigating committee as one of the ten most important technical trends of the day. Indeed, by enabling overpopulated countries with inadequate agricultural space to increase enormously their production of foodstuffs, hydroponics may eventually succeed in effecting profound social changes. The population of India, for example, increases at the rate of 5 millions a year, so that by 1990 there will be over 500 million people living within the frontiers of the union. There is no possible corresponding extension of the farmlands, and the only way to ensure that another devastating Indian famine does not occur within a generation is to get every family without land to produce their

vegetable supplies in home hydroponicums. A beginning has already been made by the work and publicity undertaken by the research institutions in the country. Overcrowded Japan faces equally serious problems. Here, three-quarters of the country is mountainous and unfit for conventional soil farming. Hydroponics has therefore much to offer the Japanese. The large-scale development of soilless techniques in North Africa would make the settlement of the Sahara possible, thus restoring to the southern coast of the Mediterranean the prosperity it enjoyed in Roman times. In Australia, the opening up of the central deserts by hydroponic means would offer almost unlimited possibilities.

SIMPLICITY AND ECONOMY

It is often thought that hydroponics is a complicated and expensive business. Nothing could be further from the truth—at any rate as far as the new simplified Bengal system is concerned. Crops can be grown very economically. In poor countries, like India, not many persons can afford to buy costly equipment. The slogan of the Bengal method of hydroponics is: 'Inexpensive to instal, simple to maintain, and economical to operate.' Suitable, with slight modifications, for any area, it has given good results in many countries. Research continues, and improvements may be expected in the future.

One of the advantages of hydroponics is the quick return. Results may be expected within three months after establishing a hydroponicum. Efficiency is maintained indefinitely. Soil, on the other hand, needs up to twenty years to be brought to full bearing. The only perfect soil is to be found in greenhouses, where periodic steam sterilization has to be resorted to—at the best a wearisome and expensive business. Soilless troughs require less irrigation than conventional beds, and loss of nutrients seldom occurs. A word of warning is, however, necessary. A hydroponic grower must follow instructions with care, if success is to be achieved. Anyone can operate the Bengal system of hydroponics with the aid of proper advice. The advantages of a method of growing crops which is not dependent on nature's whim, or the unforeseen disasters of soil culture such as erosion, drought, flood, disease, lack of manure, and other hazards, are too obvious to need recapitulation. In particular, all risk of contracting a disease transmitted through the animal excreta that is used in soil manuring is eliminated. The real merits of hydroponics are based on its value as a steady, controlled, and reliable method of intensive crop production.

Experiments have been conducted in Bengal with seed collected from plants grown in soilless cultures. There has been no evidence of any degeneracy or lack of vigour, and crops grown from hydroponic seeds of several generations

have given excellent yields. Various tests have been conducted in the United Kingdom to determine whether there are any significant variations between the fruits of plants grown in sand or aggregate, and those raised from soil. Vitamin C content was found to be identical. Analyses of carbohydrate, protein, and inorganic constituents revealed no nutritional differences. All elements were found to be present in normal quantities.[1] American experiments have shown that soilless cultivation makes it possible to produce wheat that is better for baking purposes, and to double the mineral content of tomatoes.

It has been said that artificial methods of nourishing plants are unnatural and dangerous. Although it may be perfectly true to say that artificial fertilizers used alone are often injurious in agriculture, no such charge can be sustained against hydroponics. The only legitimate criticism of chemicals is that they destroy the tilth and eventually cause erosion; consequently they should never be applied alone, but always together with substantial quantities of organic manures. But in soilless cultivation there is no soil to destroy, so this objection cannot apply.

Plants derive the greater part of their food requirements from the air, but they cannot exist without supplies of water and various mineral elements which are absorbed through their roots. Normally these minerals are drawn up from the soil, some of them originating from the weathering of rock fragments; but nitrogen, the most important of all, is produced mainly from dead vegetation and animal remains. Such organic manures cannot, however, be directly absorbed by the root hairs of green plants, but must first be broken down by bacterial action to ammonium compounds and finally to nitrates. Only then do they become of value to the crop. Thus, when farmyard manure is applied to the soil it is not until it has become converted into an 'artificial' fertilizer that it can serve for plant nourishment. Plants can only take up inorganic salts in solution; they cannot absorb anything organic. In soilless culture the mineral salts are given direct, no process of change has to occur, and consequently the nutritive requirements of a crop are immediately met. There is nothing extraordinary about this—after all, artificial fertilizers are simply the products of normal organic substances, obtained by processes similar to those occuring every day on any farm. Hydroponics is perfectly natural—it merely cuts out an unnecessary part of the life cycle, and obviates the laborious process necessary to change an organic substance into a mineral salt. Growth is also speeded up as each plant is assured of proper sustenance. Fundamentally, there is absolutely no difference between feeding crops on mineral salts, and nourishing them on organic manures; one method is merely better and quicker than the other, and more efficient.

1. R. H. Stoughton, 'Soilless Cultivation: A Review of Recent Progress', *Jour. Min. Agri.*, London, vol. XLIX, no. 1, p. 25-9, June 1942.

As a general rule the usual monthly costs for sufficient nutrients to cover one acre will be between £1 10s. and £3 or $4.20 to $8.40. Slight variations will occur according to the time of the year, the period of growth, the formulae used, or the locality. Forty hours per month is ample to allow for looking after one acre under hydroponic cultural methods. Naturally, extra labour would be required for harvesting. Large profits are possible with hydroponic gardens, and it is estimated that an average net income (after paying all expenses) per acre is Rs.20,000 (£1,500 or $4,200) a year, in Bengal.

THE BENGAL METHOD

In discussing the practical details of soilless culture, it has been decided to confine the account to the Bengal methods of hydroponics, since day-to-day operations of the various techniques are very similar, and it is considered that the Bengal system, in view of its simplicity, is most likely to be of use to the general public. Other methods are a little more difficult to reduce to the level of ordinary gardening. The Bengal system requires neither elaborate equipment nor expensive apparatus—an important consideration in countries where poverty is widespread. Units of cultivation range from the small household pots and boxes to large commercial installations covering many acres. Local considerations will always play a big part in the design and construction of any hydroponicum, and with a little ingenuity an inexpensive unit can easily be fashioned from indigenous or substitute materials. It is most convenient to deal with each item of equipment in turn, but before doing this the question of location has to be considered briefly.

Provided the essentials for plant culture—light, air, water, mineral salts, and a support for the roots—are present in some form or another, a hydroponicum may be laid down in any area. Suggestions as to possible sites have already been put forward. In the tropics, soilless troughs will be situated out of doors, in colder areas glass or plastic cloches may be utilized, with artificial heat. Protection against heavy rain, or scorching sun, is desirable. Electric lighting can be employed where there is no sun. Greenhouse benches make good hydroponic beds. A hydroponic trough is really nothing more than a bed or receptacle designed to hold in place whatever substance we intend to provide as support for the plants' roots. Troughs may be made from almost anything except galvanized iron—the excess zinc being often toxic. If galvanized sheeting has to be used it should first be given a protective coating of asphalt enamel. Wood, concrete, asphalt-impregnated mats, roofing felt, bricks and mortar, non-erodable mud plaster, iron or steel, asbestos sheets, and puddled alkali-treated clay, have all been used with success. Discarded jars, tins and basins, as well as conventional flower pots, can be

turned into hydroponic containers. Investigations are constantly proceeding with the object of testing various materials for suitability in trough construction.

Many growers of moderate means find troughs made from the non-erodable mud plaster[1] mentioned above quite satisfactory. One method of building hydroponic beds from this mud plaster is first to erect the base and framework, including the walls of the trough, in skeleton form. These are constructed with large stones placed end to end, each having been shaped as required. Successive coats of plaster are then applied to make a symmetrical and solid structure. In all cases, troughs should never be over four feet wide—to allow easy access to the plants—but they can be of any convenient length. In some commercial installations beds are often several hundred feet long. For general purposes, side walls eight inches high are satisfactory. It is a good thing to have the base slightly cambered or sloping, to facilitate the movement of solution.

The question of drainage varies according to the type of material used. Practically all kinds of troughs, except those made from mud plaster or clay, rely entirely upon a sufficient number of outlet channels to prevent water-logging and to ensure proper aeration. Small drainage holes, fitted with plugs, are always built in at regular intervals in the side walls of beds made from concrete, metal or other impermeable substances. With mud plaster, however, not only is an automatic supply of oxygen guaranteed by the steady percolation of excess moisture through the semi-porous walls (and consequent intake of air from above), but immoderate saturation of the trough is extremely unlikely to occur. Nevertheless, to guard against heavy monsoon rainfall, drainage pipes are often needed, even in plaster troughs, to run off superfluous water rapidly. Overhead matting largely eliminates such flooding. A small gutter should always be built around the base of each wall to carry away any seepage. In a household hydroponicum, where jars or pots with holes punched in the bottoms are in use, a basin or saucer placed under the receptacle will serve this purpose. The Bengal method does not call for absolutely waterproof troughs, since flooding of the growing medium is not required. It is sufficient for the containers to have reasonably solid bases and sides, so as to prevent undue escape of moisture by excess seepage or evaporation. Of course, the more solid the walls and floor of the trough the less will be the total eventual requirement of water; and the greater expense for construction must be set against the cost of water available.

In many cases, a solid foundation upon which to site troughs will be already to hand, such as roof-tops, yards, roadsides, especially if made of concrete. It is then merely necessary to construct a series of little side walls in order to complete the beds. In hilly districts, rock surfaces provide similar

1. Formula evolved by Department of Irrigation Research, Punjab, India (reproduced in *Hydroponics: The Bengal System*, p. 116).

facilities. Wooden containers must be strongly built, and require painting to prevent rot. Cement and bricks are particularly suitable for city use, while metal troughs, though expensive, would be both permanent and portable. If iron and steel apparatus is to be exposed daily to the full glare of the tropical sun, it is essential to insulate it by a thin encasement of plaster to prevent undue heat radiation. Asbestos sheeting has many advantages; it is strong and durable, and can be cut like wood, but in most cases local considerations will determine the substance most suitable. Indian peasants have even made beds from ordinary mud, fortified with chopped straw and glutinous cow manure, which gave excellent service. To prevent these beds from being washed away during the monsoon, these resourceful cultivators had carefully covered each wall with a lattice-work support of thin bamboo.

The troughs, when completed, are filled to a depth of eight inches with coarse inert aggregate. This should consist of a mixture of five parts of gravel, stone chips, broken brick, or leached cinders, of five-eighths to one-quarter inch grade, and two parts of sand or rock dust. This mixture, which is one of the novel characteristics of the Bengal system, constitutes the support for the plant roots. Actually many different types of aggregates or growing mediums are employed, each varying a little according to the particular method adopted. Instead of gravel or chips, vermiculite or collite may be used, while, for sand, either peat or sawdust could be substituted. The most critical factors in the choice of a growing medium are, first, to ensure that it is not likely to suffocate the plants by preventing aeration of the roots, and secondly, that it will be capable of holding moisture. Too coarse an aggregate will dry out quickly. On the other hand, a very fine medium, such as pure silver sand, may be liable to waterlogging during wet periods. If, however, a larger aggregate is unprocurable and sand has to be used, at least a layer of small blocks, two inches deep, should first be placed on the trough bottom. In mountain areas big boulders are plentiful and can be broken up to a suitable size. The grade of medium resulting consists naturally of both rock chippings and dust or sand. The ratio of five to two, already mentioned, may be subject to variation. In a cold area, where evaporation is not so great, the quantity of coarse aggregate in the growing medium can be increased, whereas in a desert area, when great dryness and a high temperature exhaust the moisture content in the troughs rapidly, a lower amount of gravel and more sand can be utilized. Sand or stones alone are not satisfactory. The best gravels are low in calcareous content. Cinders need to be well leached, by soaking in water for some days before use. Very alkaline or acid substances require suitable treatment before use as aggregates.

In a large hydroponicum some apparatus has to be devised to convey water to the aggregate-filled trough, so that the growing medium can be kept moist without undue effort. A rubber hose can do this most easily and quickly, but use may also be made of some form of guttering. In country

districts in tropical countries, bamboos can be cut and split down the middle. When joined and fixed on level supports, they make an ideal water channel. A stirrup pump or a garden can fitted with a rose is necessary for washing in the nutrient salts after application. A simple spreader has been devised to speed up the dry sprinkling of fertilizer salts. This consists of a slender cone made from tin sheet-metal, the apex of which has a series of holes similar to those of a pepper pot, while the base is made to open. The use of a pair of scales or a spring balance of reasonable accuracy is essential if the grower intends to apply his nutrients by weight, otherwise a spoon or some definite fixed measure of capacity is required. Apart from these items no other equipment is necessary except certain ordinary garden tools, such as fork or rake. The screens or straw mats which provide overhead shade from the tropical midday sun and shelter from monsoon rain and hail also ensure that the growing medium remains cool, and they check transpiration and evaporation. In cold areas, electric cables can be run under the aggregate to enable heat-loving plants to be grown out of season. For commercial nurseries with trained personnel, a pH testing outfit is useful, as well as pumps, air-conditioning plants, or tanks. But the ordinary man can manage with just a jug, a spoon and a few tins filled with aggregate.

A regular and reasonably clean water supply is an essential part of the hydroponic apparatus. In practice, however, natural water generally contains various substances, and its composition varies from area to area. In hydroponics, a water is judged by the various quantities of mineral salts which it contains. Should salinity rise to over 2,500 parts per million, it would prove toxic to the green plant. As a matter of interest the salinity of some waters is given in Table II.

TABLE II.

Location	*p.p.m.*
Bahrein Island (Persian Gulf)	2,220
River Thames (London)	270
Mississippi River (New Orleans)	166
Lake Superior (Michigan)	58
Lake of Zürich	141
River Nile (Khartoum)	174
River Rhine (Strasbourg)	204
River Seine (Ile-de-France)	252
River Hudson (New York)	112
River Brazos (Texas)	1,066
River Danube (Regensburg)	204
River Arkansas (Colorado)	2,134
Lake Huron (Michigan)	105

It will be seen that for all practical purposes, most waters are quite suitable for plant culture. In large commercial hydroponicums it is advisable to have

the water analysed, chiefly in order to economize on the amount of nutrients used. But the ordinary grower need only know whether the water supply is alkaline or acid. Rain water is usually neutral, and is consequently ideal for soilless cultivation. When appreciable quantities of nutrients are present in the water, a corresponding reduction in the mineral salts applied is desirable.

The main elements which must be supplied to plants growing in a hydroponicum are the same as those needed by crops under ordinary conditions. A proper concentration must be assured, and a satisfactory equilibrium maintained. The desirable proportions are as shown in Table III.

TABLE III.

Element	*p.p.m.*
Nitrogen	200-400
Potassium	100-200
Phosphorus	80-100
Magnesium	50-100
Calcium	300-500
Iron	2-10
Manganese	0.5-5
Boron	0.5-5
Copper	0.5
Zinc	1

The above nutrients may be supplied either in the form of mixtures of fertilizer grade salts or in the form of synthetic resins, such as amberlites. Salts can be compounded into tablets, or into packeted powders. Several hundred different mixtures have been proposed for hydroponic use, but the actual salts utilized are of little consequence so long as the proportions of the elements are right. Commercial grade fertilizers are satisfactory. Any reputable manufacturer, pharmacy, horticultural or agricultural firm can easily prepare any formulae from a prescription. No doubt for the general public ready-mixed nutrients would be the simplest to use, and make the spread of hydroponics easier.

The idea that there must be some 'best' mixture for hydroponics has haunted investigators for many years. Up to now no such formula has been discovered. In practical work, the variation of a few grammes in a mixture has no appreciable effect upon results. For the sake of simplicity, every effort has been made to keep the formulae in the Bengal system as simple as possible.

Climate also plays some part in deciding upon the ingredients of any mixture. In a tropical country, such high concentrations as those used in northern latitudes are unnecessary. Brilliant sun and high light intensity during the dry season enable growers in India to reduce the supply of potassium in many cases by 50 per cent. However, during the monsoon it may have

to be restored to nearly normal. In Europe, a good potash content is essential owing to the dull and cloudy weather. Generally speaking, when plant growth appears slow, additional but not excessive quantities of nutrients should always be applied. It must be borne in mind that one of the main features of the improved and simplified Bengal method is economy in fertilizers, while the special technique employed effectually ensures that no wastage of salts takes place.

The following mixture has been used with considerable success at the experimental centres in India:

Fertilizer	*Ounces*
Nitrate of soda	5 to 6
Sulphate of ammonia	3
Calcium sulphate	1.5
Superphosphate	3 to 3.5
Potassium sulphate or muriate	4
Magnesium sulphate	2.5
Trace elements[1]	0.25 dram

1. Two ounces of trace element mixture consists of: zinc sulphate, 3.0 dr; manganese chloride, 9.0 dr; boric acid powder, 7.0 dr; copper sulphate 3.0 dr; iron sulphate, 10.0 dr; a total of 32.0 dr.

This is applied at the rate of two ounces per week, or per 10 days, to each square yard of trough space.

Other formulae are quite practicable, and if any particular salt is unavailable, another should be substituted. The major nutrient salts should be well mixed together, and any lumps broken up into a fine powder. Nutrients should never be allowed to get damp or wet before application. For this reason a dry bin or tin to keep them in is essential. Many chemicals are, of course, hygroscopic, hence this precaution. Generally speaking, two ounces of nutrient mixture will last one square yard of trough-growing medium for up to a fortnight. If it is desired to add the compound to a water supply, 30 ounces dissolved in 100 gallons should be given weekly as a solution. This would suffice for 15 to 20 square yards of trough surface space. Useful modifications are dealt with in the literature available about the Bengal system. Different crops have certain preferences, and special formulae can of course be prepared with advantage for each type of plant; but for practical work of a popular nature one general mixture, such as that listed above, will suffice. If a water is extremely alkaline, a little sulphuric acid may be added to it at the rate of not over one-quarter fluid ounce per 100 gallons. Similarly, an acid water may be treated with dilute alkali. The reaction of the solution which is formed when the nutrients are watered in should approximate to pH 6.0 for most crops. Some plants, like potatoes, need a slightly more acid solution. Periodic tests of the moisture contained in the

growing medium are useful as a check. Tabloid nutrients, or compounded mixtures, should give a suitable pH reaction when added to the irrigation water. The usual colorimetric tests are quite satisfactory. The technique of using tablets is to insert them deep down in the aggregate near the root zone, or else to crush them up and apply as a powder. In any case, solubility is of vital importance.

The other method of supplying nutrients is to add them to the aggregate by means of synthetic resins, such as amberlites, which have ion-exchange properties. By incorporating a quantity of them in the beds at the beginning of the season sufficient nutrients can be made available to the plants all through the growth period, only the addition of water being necessary. Complications of nutrient management are avoided, and there is reduction in losses from leaching and in the labour required. This method is still in the early stages but results so far obtained have been encouraging.

ACCOUNT OF THE BENGAL TRIALS

An account of the first trials at the experimental sectors in Kalimpong, which resulted in the introduction of the simplified methods of soilless cultivation, will indicate the day-to-day working of a soilless unit. In the early autumn of 1946, the first troughs were constructed in the station near Darjeeling, three types of beds being laid down: small wooden containers, large beds of non-erodable mud plaster, and other troughs with concrete bases and plaster side walls. All proved quite satisfactory. Irrigation was supplied by bamboo gutters and a rubber hose. Small containers were watered with a garden can. The growing medium was a mixture of chipped mountain boulders, and rock residual dust. In some cases seed was sown directly into the aggregate, but experience indicated that the best results could be obtained by germinating those with a diameter of under one-fourth of an inch in separate boxes containing sand or some other fine inert medium, and subsequently transplanting the seedlings when they had attained a height of three inches. Cereals and legumes were not transplanted and had to be spaced out properly in the beginning. Before sowing, the aggregate was brought to the correct degree of saturation, dug over with a fork or trowel, and raked smooth. Any litter or refuse was removed. In soilless culture, there should be no weeding necessary, and weeds at no time proved any problem. No seeds of any variety were sown at a depth of more than two inches. The smaller the seed, the lighter its covering of aggregate had to be, and experiments soon showed that it was virtually impossible for a young shoot to force a way up from any greater depth. In fact, for tomatoes and other small seeds a quarter of an inch was ample.

All crops were grown in straight rows parallel to the width of the bed, so

that nutrient salts might be applied without any difficulty. Plants invariably established themselves immediately without wilting. The operations of sowing and transplanting called for skill and care, and attention was needed to ensure that the beds were at the right degree of saturation—just like a damp sponge lightly wrung out, not too wet nor too dry. Nutrients were applied to the growing media, weekly at first, and later at intervals of a fortnight. An average of two ounces per square yard of trough surface was used. The specified amounts of chemicals, having been weighed out, well mixed, and blended with an equal quantity of fine dry silver sand to act as a filler for easy flow, were placed in the metal cone spreader, and while dry, were gently shaken evenly between plant rows. Care was taken to ensure that no chemical fell on the plants' foliage. Immediately after application, the nutrients were well watered in by a spray from the stirrup pump, or by the garden can or hose fitted with a rose. With amberlites, of course, only one application was required—a deeper 'burial' of the synthetic resins in the aggregate and even distribution throughout the bed of the quantity needed for the growth season. Potassium nitrate was mixed with the irrigation water weekly. Prepared tablets were inserted four to five inches deep in the aggregate, if soluble within a day or two; if not they were crushed and applied as an ordinary powder mixture.

In temperate zones, water consumption in hydroponics does not exceed that needed for soil cultivation. In tropical areas, hydroponics compares favourably with soil cultivation in this respect. It was found in India that a trough of 1,000 square feet required about 200 gallons per day to keep it suitably moist. One of the greatest troubles in hot and dry areas—that of water—has been partly overcome by the introduction of a simple means of constructing portable sets which automatically distil fresh water from brine, for use in vegetable cultivation in arid desert or barren sites with a continental climate. At the seaside or in the wilderness, saline water will be available, or in many places there may be brine present as ground water. A contraption like a dome or hut of glass or metal acts as condenser. Under this the salt water is run into a series of trays surrounding a central column of paraffin wax or calcium chloride possessing great latent hardening temperature. The hot sun shining in the daytime evaporates the water as vapour, leaving the salt in the trays. At night the rapid cooling of the dome turns the trapped vapour back into water, which then runs down the inside of the cover, and out on to the beds through exit pipes. The trays are cleared and refilled for the next day. By this simple and portable device, a constant supply of fresh water can be secured from the most unpromising sources.

PRESENT STATE OF DEVELOPMENT

It may be of interest to give a very brief summary of the present state of development of soilless cultivation in countries where it is now being carried on. Naturally, methods vary a good deal, and different groups of investigators have tackled the problem from different angles.

In India, following upon the successful results obtained with simplified techniques of hydroponics at the Government experimental station in North Bengal, efforts have been made to extend soilless cultivation throughout the sub-continent. A demonstration centre is being opened by the Government of Bombay at Aarey. Several thousands of enthusiasts have started small units in all parts of the country, and there are several larger installations in Calcutta. The future looks most promising. A great many inquiries, requesting advice and literature, sometimes over one thousand a month, are received at the hydroponic information centres, and at the Agricultural Institute, not only from India, but from Pakistan, Burma, East and South Africa, New Zealand, Australia, Malaya, Formosa, the Seychelles, Guiana, the United Kingdom, Malta and Aden.

In the United States, many different systems of soilless culture are in use. As the original home of the idea, the United States probably shows more development than any other country. Unfortunately, under the American techniques, hydroponics is very often too complicated to prove of value to the general public. But where equipment can be afforded, and skilled labour is to hand, soilless cultivation has done very well. The main areas utilizing it are California in the west—where a large part of the tomato crop is raised by this method—Florida, the Middle West, and the eastern seaboard states. The army has set up a special hydroponics corps, and issued a manual[1] for the guidance of its personnel engaged on producing crops by this means at isolated military bases. An account of this development is given by Stuart[2] in an interesting paper. Many large nurseries are using hydroponics for floriculture.

In Japan, the units at Chofu and Otsu, operated by the United States occupation forces, total over 80 acres. Enough vegetables have been grown soillessly to feed all the troops stationed in Japan. Other installations have been opened on Iwojima.

The Guiana and Ascension Island hydroponicums are also operated by the United States Army. At Atkinson Field, over seventy-five beds have been built. The cost of producing a pound of cucumbers in hydroponics is $0.04 against $0.11 in soil, for tomatoes it is about equal.

In France, work has been undertaken by Chouard.[3]

---

1. *Nutriculture*, War Dept. Tech. Man., 1946.
2. N. W. Stuart, 'Growing Plants Without Soil', *The Scientific Monthly*, vol. LXVI, no. 4, April 1948.
3. P. Chouard, *Cultures sans sol*, La Maison Rustique, Paris, 1954.

In the United Kingdom pioneer activities were begun at the University of Reading in the horticultural department. The method favoured is sub-irrigation. Other work has been carried out at the Experimental and Research Station, Cheshunt, Herts., and at Jealott's Hill Research Station. There are complications, but all these institutions have reported favourably on the use of hydroponics. Some large nurseries have undertaken carnation and salad culture by soilless means.

Much work has also been done in the Dutch West Indies by the local oil companies on Aruba and Curacao, where big hydroponicums exist to supply the employees with fresh foodstuff. In Iraq there is soilless culture at the RAF bases.[1]

To sum up: hydroponics has already reached the stage where it is a practical proposition; it is profitable in almost any conditions; and it is invaluable as a means of food production in countries or areas which have not enough fertile soil to feed their population.

1. R. H. Stoughton, *Soilless Cultivation on Desert Airstations*, The University, Reading, 1945.

BOOKS AND PUBLICATIONS

Blood Groups and Racial Groups

A. E. Mourant, *The Distribution of the Human Blood Groups,* with a foreward by Professor H. J. Fleure, F.R.S., Blackwell Scientific Publications, Oxford, xxi + 438 p., 42s.

When a man says, 'So-and-so has Irish blood in his veins', he is using an everyday figure of speech. There is a very ancient belief that the blood is a fluid of infinite complexity, which carries the stamp of individuality, the very life spirit of a man as well as the character of race. The remote origin of this belief is suggested by the widespread distribution of myth and symbolism concerning the blood among primitive populations, today as in the past. The almost mystical association of blood with family or race is reflected in the terms 'blood feud' and 'blood brotherhood'. Blood brotherhood is a pact or alliance formed between two persons by a ritual act involving the exchange of blood. The pact is one of mutual assistance and is backed by powerful sanctions. It is nearly as binding as the ties of kinship, and the exchange of blood appears to be a kind of substitute for these ties. Variations of blood brotherhood have been recorded from many parts of the world. The belief that the blood embodies the soul or spirit (*pneuma* or *anima*) of every living creature has also been very widely held. The blood in this case seems to be more than just a symbol, although it is often used as an 'outward sign' or symbol in magical ritual. If Frazer is right (and there is still a strong body of opinion in support of his interpretation), many taboos are based upon the belief that the soul or spirit of an animal is in the blood. Thus, it is recorded of Esthonians, North American Indians and others that they would not taste blood because they believed that it contains the animal's soul, which would enter into the body of the person who tasted it. The individuality of the blood is implied also in the use of the term 'royal blood', which is again associated with numerous taboos.

When attempts were first made to transfuse blood from one animal to another, they were sometimes successful, but they often provoked severe or even fatal reactions in the recipients. From this result the early Fellows of the Royal Society in seventeenth-century England concluded that the ancient belief in the complexity and individuality of the blood was well founded. It was natural for Mr. Robert Boyle, when writing to Dr. Richard Lower, to speculate 'whether the blood of a mastiff, being frequently transfused into a bloodhound, or a spaniel, will not prejudice them in point of scent'.

If each person's blood were to express its individuality as they supposed, blood transfusion would be a hazardous procedure indeed. The attempts to transfuse blood had failed for a much simpler reason than was foreseen by the eminent Fellows of the Royal Society. Further understanding of compatibility and incompatibility of the blood was delayed until the discovery of the blood groups by the great serologist Landsteiner in 1900. This, in turn, grew out of the study of immunity which was one of the striking

achievements of the young science of bacteriology at the end of the nineteenth century.

Landsteiner recognized that when blood samples from two human beings were mixed, clumping or agglutination of the red cells sometimes occurred. He was able to demonstrate that all the observed reactions could be explained by assuming that red blood cells have on their surfaces two different chemical substances, A and B. These substances are each capable of reacting with a specific serum protein or antibody, which brings about the clumping of the cells concerned. According to whether their cells contain one (A), the other (B), both (AB) or neither (O) of the two substances, human beings could be classified into four groups. Cells of group O are not normally agglutinated and they can be transfused into any recipient with comparative safety. Persons with the relatively common blood group O are therefore termed 'universal donors'.

Later, several other blood groups were discovered in red blood cells by means of special techniques involving the artificial production of antibodies in animals. In this way the M and N groups were discovered in 1927 and the Rhesus (or Rh) groups in 1939. The Rhesus groups soon assumed great practical importance, since it was shown that immunization against Rhesus groups quite commonly takes place in man as a result of blood transfusion and pregnancy, where it may be responsible for serious transfusion reactions and injury to the unborn child.

During the war years the use of blood transfusion expanded greatly in both military and civilian practice. Research into the hazards of blood transfusion was also intensified. It soon became clear that several Rh blood groups are present, and these have been termed, by Sir Ronald Fisher and Dr. R. R. Race, C,D,E,F,c,d,e and f. Other variants of these groups also occur. A number of other blood group systems, independent of one another in their reactions and inheritance, were subsequently discovered by careful examination of blood specimens of patients who had reacted unfavourably to transfusion. In all, at least forty-two relatively common groups belonging to nine separate systems are now known, and each year brings new discoveries.

In 1924 the exact method of inheritance of the ABO groups was worked out by the mathematician Bernstein. He showed that the groups A, B and O are inherited as Mendelian characters by means of three genes. The A gene is responsible for the production of A substance in the red cells, and the B gene for B substance; the O gene does not give rise to an antigen detectable by ordinary methods. One such gene occurs on each of a pair of chromosomes possessed by all humans. Every child receives from each parent one chromosome bearing one of the three genes, A, B or O, which can therefore come together to give six possible genetic combinations. The inheritance of the other groups follows similar lines and is well understood, although in some cases it is quite complex. Thus the Rh groups are controlled by four genes situated very close to one another on each of a pair of chromosomes. One of these chromosomes will be passed on intact from parent to child in reproduction.

The study of the human blood groups has resulted in some important practical applications. The most direct application lies in the practice of blood transfusion. Landsteiner's discovery made blood transfusion possible; subsequent

work, especially the recognition of Rhesus immunization, has made it a comparatively safe procedure. Elaborate precautions are taken to ensure compatibility of blood between donor and recipient, and the number of cases showing unfavourable reactions is only a small fraction of all those being transfused. In England and Wales alone, more than half-a-million pints of blood are drawn for use every year. Blood transfusion occupies an honourable place among the life-saving measures that have revolutionized medical and surgical practice during the past twenty years.

The second important application of blood group studies to medicine lies in the causation of a relatively common and serious disease long recognized among newborn children. In 1940 it was discovered that if an Rh negative mother is carrying *in utero* an Rh positive child, the blood of the child sometimes enters the circulation of the mother. In the mother's circulation antibodies against the Rh factor are formed, and these are able to cross the placenta and enter the blood of the child, where they destroy the circulating cells. In this way a serious, or even fatal, anaemia is produced. Since the immunization of the mother is more complete after repeated exposure to Rh positive blood, the effects are usually more severe in the second and subsequent pregnancies than in the first. If the woman has received a transfusion of Rh positive blood before the pregnancy, even the first child will be seriously affected. Perhaps the most important medical aspect of the Rh factors is the realization that harm can be done by transfusing females before, or during, the child-bearing period, without first finding out the Rhesus groups. The discovery came just in time; for owing to the war transfusion facilities were well organized and transfusion might have become almost a routine practice in obstetrics, with disastrous results in ignorance of the Rh groups. In about 14 per cent of Western European marriages the husband is Rh positive and the mother is Rh negative. Fortunately Rh immunization does not occur in every such marriage. And, even when it does occur, the lives of many children can now be saved by replacing their blood, immediately after birth, with Rh negative blood.

Since so many blood groups are known, the number of possible combinations is tremendous. In fact, several million genetic combinations can already be defined. Some of these possible combinations are so rare that, in the words of Race, 'they may never have formed the blood of an Englishman'. Others are less rare, but even when sera now fairly generally available are used, the great majority of persons in any small sample have distinctive blood group combinations. When the staff of the Lister Institute in London were tested for nine blood group systems, they were found to belong to 129 different blood group combinations, of which 126 occurred only once and 3 occurred twice. Thus if a second, unlabelled series of blood samples had been sent for testing, 126 of the 132 samples could have been correctly identified. When more antisera are used, the pattern will become even more distinctive, so that before long it will be as distinctive as the finger print. Thus in a very real sense, but in a sense completely different from that foreseen by men of former generations, the blood is highly individual. Fortunately, this uniqueness of blood group combinations only occasionally affects blood transfusion, since most of the groups rarely stimulate the production of antibodies in recipients.

Practical use can be made of the individuality of blood group combinations.

The commonest type of medico-legal problem to which blood groups are applied is cases of disputed parentage involving children born out of wedlock. Any character that is to give unambiguous evidence regarding parentage must be simply inherited and its mode of inheritance must be known with certainty; it must be developed to a recognizable degree at birth or soon afterwards; and it must retain its distinctiveness throughout life unobscured by age, disease, climate or any other influence. Since the character is being used to settle a dispute, it must be clearly recognizable by objective and reproducible procedures. The blood group tests are the only ones at present available which fulfill the requirements.

A simple example will suffice to illustrate the relevant principles. If a mother has blood group O and her child is A, then the father must have been either A or AB. Any man whose blood group is O or B can be excluded from the responsibility of parentage. Using seven different blood group systems available in most well-equipped laboratories, about 62 per cent of Englishmen wrongfully accused of paternity by Englishwomen could be excluded. It is never possible to *prove* paternity beyond all doubt, but sometimes paternity can be indicated with a very high degree of probability, provided that the brothers of the accused have alibis.

Blood grouping tests have now become a standard procedure in cases of disputed parentage in the American courts. In many Western European countries, also, routine blood grouping tests are carried out in laboratories supported by the government. A recent publication from the University Institute of Forensic Medicine in Copenhagen, for instance, quoted the results of 20,000 tests for paternity exclusion. In Great Britain and the Commonwealth countries, however, blood group tests have been carried out to only a limited extent, presumably because the present state of the law is unsatisfactory. In 1938 Lord Merthyr introduced his Bastardy (Blood Tests) Bill into the House of Lords. Early in 1939 it reached its second reading, and was sent to a select committee. The committee made some amendments to the Bill which they then recommended should be 'passed into law'. Then the war began and the Bill lapsed. The proposed law would have made it possible for the court, or either party, to demand blood tests. The tests were to be done in special laboratories, one in England and one in Wales. It was proposed in the Bill that only registered medical practitioners should be allowed to do the tests, but this provision would exclude some of the foremost authorities on blood groups and genetics. Clearly the person who carries out the tests should be a specialist with considerable experience and access to a large panel of people who could be called upon to act as controls for the various tests. Such a panel of recognized specialists could be set up without difficulty.

Other problems of identity arise in the course of genetical investigations. Extra-marital children are common enough in most countries seriously to disturb the accuracy of statistics on inheritance. Blood grouping tests can then be applied to exclude paternity in the usual way, the results being, of course, confidential and withheld from the husband. In twin studies, also, it is of the greatest importance to establish unequivocally whether a given pair of twins arises from one or two fertilized eggs, that is, whether the partners have the same or a different genetic constitution. If the blood groups are different, it can be stated categorically that the twins are binovular, arising from separate eggs. If the blood groups are the same the chances of the twins being uni-

ovular can be calculated, and they are usually of the order of 97 to 99.9 per cent. Comparison of uniovular and binovular twins is a powerful method for the investigation of genetic and environmental influences on the development of mental and other attributes.

There is another way in which the blood groups are of great value in human genetics. Since they are common characters, they serve to mark the chromosomes on which they are located. Other heritable characters whose genes are situated on the same chromosome as any blood group gene should be transmitted together with it to the next generation, i.e. the two genes should be linked. Linkage is well-known among the blood groups themselves; the gene for the S group, for instance, is linked to the MN system, and it is very probable that the Lewis and Lutheran blood group genes are linked. The gene which causes the A and B substances to be liberated into the bodily secretions is linked with the Lewis gene. Recently a linkage between an outside gene (that responsible for the development of elliptical instead of discoid red blood cells) and the Rh system has been discovered. The search for linkage has only just begun in earnest, and doubtless many other examples will soon come to light. This represents an important achievement in human genetics. Eventually it should prove possible to prepare a map of the chromosomes of man, with the positions of genes indicated on each chromosome, as has been done in the much simpler case of the fruit fly *Drosophila*. The map would be of practical value as well as theoretical interest, since the chromosomes carrying potentially disease-producing genes could be identified and corresponding eugenic advice given to the families affected by these conditions.

Blood group tests can also help in the identification of stains. Problems of this type arise in connexion with murder cases, as when the suspect is found with blood stains on his clothing for which he cannot account. In New York City, a special department examines the blood groups of all persons who have met their death through violence or in suspicious circumstances, and any stains of blood or secretions that may have a bearing on the case. As a result of routine testing of such stains and blood obtained *post-mortem,* it has been possible to solve a number of puzzling murder cases, as well as hit-and-run motor cases.

The uniqueness of blood group combinations applies not only to individuals but also to races; and this is the main topic discussed in Dr. Mourant's book. Each racial group is characterized by distinctive blood group frequencies. The first evidence in support of this view was contributed by two Polish doctors, Professor and Mrs. Hirzfeld. They were working in Salonika during the first world war and were able to do blood grouping tests on personnel from many different countries. It was at once apparent that the frequencies of the several groups varied considerably from one racial group to another. An enormous amount of investigation has demonstrated that this is true in the case of almost all the known blood groups. Certain blood groups are not uncommon in some races, but are extremely rare or absent in others. It follows that if complete tests are made on two samples of blood, say one from a European and one from an African Negro, there is a good chance that the samples could be correctly identified. Given two series of three samples each, one series African and the other European, the series could be identified with a very high probability of success.

For many years it was thought that blood group differences between the races were nearly ideal for use as racial characters. The incidence of the various groups can be found directly by testing; the inheritance is known; and the frequencies of the genes themselves can be calculated. In this way the genetic constitution of different populations, the very units of heredity that are handed down from generation to generation and give the race its lasting character, can be studied. The gene frequencies also lend themselves readily to analysis by statistical methods. It was thought that the genes would assort themselves at random when racial mixture took place.

This interpretation rests on the assumption that the blood groups are neutral from the point of view of natural selection, in other words that blood groups are perfectly harmless characters having no effect on the health, viability or reproductive capacity of the possessor. For many years this assumption was accepted, and the blood groups were supposed to be handed down from generation to generation without producing any selective effects: to drift purposelessly and in a random way through populations. Recent evidence indicates that this view is very probably mistaken. Sir Ronald Fisher has demonstrated mathematically that genes which are neutral from the point of view of natural selection must be rare. The continued presence together of several alternative blood groups in a population (e.g. A, B and O; Rh positive and Rh negative) is probably the result of selective forces operating so as to increase the frequency of each group up to a certain level, after which the advantage is checked. Since 1940 it has been known that blood group incompatibility between a mother and her unborn child is responsible for a severe, and often fatal, anaemia in the newborn child. In this case the possession of certain blood groups will increase the likelihood that the child will be affected, i.e. there is a direct selective effect. It is now known that the blood groups are associated with the susceptibility to certain diseases in a less direct way. Children with group A appear to be more liable to die of pneumonia than other children, and adults with blood group A more frequently have cancer of the stomach than adults with other blood groups. On the other hand, those with blood group O are especially liable to develop peptic ulceration. It is therefore highly probable that the blood group equilibrium is maintained by selective forces which favour one blood group gene in certain circumstances and other blood group genes in other circumstances.

A situation very similar to that of the blood groups has recently been found. It concerns another gene affecting the blood, the so-called 'sickle-cell gene', responsible for the presence in the blood cells of an unusual type of haemoglobin pigment which can distort the cells into a sickle shape. One sickle-cell gene is present, together with one normal gene or allele, in a great many indigenous Africans, as many as 40 per cent of the people in certain tribes being affected. When the sickle-cell gene is inherited from both parents, however, one such gene being present on each of a pair of chromosomes, a serious haemolytic anaemia develops, which is often fatal in childhood. Here we have the paradoxical situation where rapid elimination of genes from a population (far too rapid to be replaced by new mutations) does not lead to the disappearance of the gene at all. In fact, the gene continues to be common over a wide area. The paradox has been at least partially resolved by the demonstration that the persons who possess one sickle-cell gene are naturally resistant to malignant tertian malaria, which is an important cause

of mortality in African children. Thus the presence of the sickle-cell gene is advantageous in one situation and detrimental in another. The fact that Africans have continued to be divided or polymorphic for this character is the resultant of selective forces in favour of and against the gene concerned. It can be calculated that the advantage of possessing one sickle-cell gene in a malarious environment must be relatively enormous: the possessor has about a 20 per cent greater chance of surviving to reproductive age than have his relatives without the gene. If the environment were to change so that malaria ceased to be significant, it would be expected that the selective disadvantage would continue without the operation of the compensatory advantage. Hence the equilibrium would cease and the frequency of the gene would fall rapidly. The available figures suggest that such a fall must actually have occurred among the Negroes who were transported to the New World, and that it is of the anticipated order of magnitude.

In general, the observations on the blood group genes and the sickle-cell gene indicate strongly that natural selection has been acting, and still continues to act, on human genes. The action is powerful enough to produce a distinct change in the genetic constitution of human populations in a few generations. That is simply another way of saying that evolution of man has been taking place not merely in measurable time but within the short space of a few hundred years. It has often been stated that natural selection is not effective in human populations because they are sheltered, and not bound up with the 'struggle for existence'. This view is untenable. Disease must be a powerful agency in evolution, and hereditary resistance to disease must have considerable 'survival value'. The selection in favour of the sickle-cell gene in malarious environments, but not elsewhere, is a case in point. There will be survival of the 'fittest' in every sense of that word.

We must therefore approach the available data on blood group distribution, so conveniently summarized by Mourant, from an entirely fresh viewpoint to find out whether they show any evidence of selection. We find, in fact, a general uniformity of blood group distribution over large areas, and, what is more convincing, a close resemblance between populations known to have a common origin but to have been separated for long periods of time. This tends to support the earlier hypothesis that a common origin between peoples leads to a long-maintained similarity in their blood-group distribution. The problem can be stated in another way: how long will such similarities be maintained? The answer seems to vary from one system of blood groups to another. It is at first sight surprising to find that the Rh blood group frequencies, subject as they are to selection by death from haemolytic disease of the newborn, should appear to be stable and uniform over large areas of continental dimensions. Thus the Rh gene combinations in indigenous Africans tend to vary little over the whole continent, even though they are markedly different from the combinations found in Europe. And the frequency of the typically African combination cDe in coloured populations is a fairly reliable index of the degree of African admixture. Although the ABO groups are much less subject to selection by haemolytic disease, the frequencies vary widely over much smaller distances. This variation, against a stable background of the genes of other systems, suggests that, in relation to other genes, the ABO genes are intensively selected by the environment. The discovery of a connexion between these groups and disease shows that such selection can occur.

The ABO antigens, or substances chemically very similar to them, are known to be present throughout the animal kingdom, and even in bacteria. Part at least of the MN and Rh systems is common to the whole order of primates. The continued existence of species polymorphic for characters of this type, in other words, the fact that one or another of the groups or systems has not died out, suggests that the equilibrium between the groups is in the long run remarkably stable, although in the short run quite large variations can occur. Mourant estimates that the following orders of time are necessary for appreciable genetic changes to occur through selection: in the case of the sickle-cell gene, a few hundred years; in the case of the ABO groups one or two thousand years: and much longer in the case of the Rh and MN frequencies. Thus even the short run changes cannot take place very rapidly, so that the blood groups are still, and will remain, valuable characters in tracing long-term ancestral origins.

A few examples will illustrate how blood group differences run parallel to those shown in other racial characters. They will also illustrate how useful blood groups can be in anthropology. The Basques, at present a small population in the Western Pyrenees, are nevertheless of great importance in the study of European anthropology. The Basques speak a language which is unique in the world, and their skeletal measurements are said to show features resembling those of the late palaeolithic inhabitants of Europe. The blood groups faithfully reflect the distinctness of the Basques from other modern European populations: the Basques show remarkably low B frequencies and the highest Rh negative frequencies so far known. Indeed, it has been supposed that the forerunners of the Basques may have contributed the Rh negative genes now widespread in Western Europe. The Béarnais, who are neighbours of the Basques in south-western France, but are distinct from them, show the same remarkable blood group frequencies. The only other people who approach these frequencies are certain Berbers from the Great Atlas Mountains in North Africa. The blood group evidence thus suggests that in paleolithic times there was a link between the populations of the Iberian peninsula and North Africa; and this is consistent with other archaeological and anthropological evidence. Again, the Finns, in spite of their Finno-Ugric language, closely resemble the East Baltic peoples in blood group frequencies but are quite distinct from the Lapps, who also have a Finno-Ugric language. From this and other evidence it seems probable that the Finns were originally Indo-European speakers, like the Latvians and Lithuanians, and that they took over the Finno-Ugric language from some Lapp-like people between one and two thousand years ago. Moreover, there is a fairly close resemblance between the Polynesians and the American Indians in respect of most blood group systems. Hence the blood group data are at least consistent with the hypothesis of an American origin of the Polynesians. Interpreted with discretion, blood group findings are of definite value in prehistoric and historic research, but we cannot expect blood groups to provide answers to all the riddles that have faced physical anthropologists for years. It seems, indeed, that a kind of uncertainty principle is operative in physical anthropology. Given that selection does not modify the genetic constitution of a population, we can accurately calculate probable origins and the outcome of miscegination. But once the effects of selection are recognized, such calculations become faulty. The more powerful the selective

effects, the more uncertain will the calculations become, and the more blurred and indistinct will the origins of the people concerned remain.

Of one thing, however, we can be sure. The blood group evidence unites with other evidence to show that there is marked heterogeneity in the genetic structure of all the racial groups living today. The races are, as Mourant states, 'but temporary integrations in the constant process of mutation, selection and mixing that marks the history of every living species that maintains itself by sexual reproduction'. Another general conclusion can be drawn. The existing differences between the races of mankind are the outcome of both genetic and environmental factors. The influence of environment has been discussed briefly elsewhere,[1] when evidence was summarized indicating that the environment plays an important part in the development of physical and mental traits; and the genetic constitution of a race is by no means static, since it is subject to alteration by selection. The genetic diversity is not confined to the blood groups. Every race contains a tremendous amount of variability or potential for development in different directions. One type of variability has already been discussed, where several alternative forms of a particular character occur together in a population. Before any dogmatic pronouncements concerning racial abilities and limitations are made, these two factors should be borne in mind: that environment plays a powerful role in moulding the expression of hereditary propensities, and that all races have an enormous amount of concealed variability. The variability can be explored in only one way, through the direct application of the experimental method. By giving 'backward' peoples education, specialized training and responsibility, their inherent capabilities will express themselves in a few generations. By denying them these opportunities, the potential will continue to lie dormant, as it may have done for centuries.

ANTHONY ALLISON
Department of Pathology
University of Oxford

1. *Impact*, vol. V, no. 3, p. 191-200.

BULLETIN OF THE ATOMIC SCIENTISTS

This 'Magazine of Science and Public Affairs' undertakes to provide an objective review of facts and to give expression to different thoughtful opinions on the issues raised by the discovery of nuclear energy and, more generally, on the mutual relationship of science and society.

RECENT ARTICLES

Can We Sleep Soundly in the Shadow of the H-Bomb?	*Hans Thirring*
Prospects in the Arts and Sciences	*J. Robert Oppenheimer*
The Arms Stalemate Ends	*David F. Cavers*
'By Man Came Death'	*Sir Llewellyn Woodward*
Scientists, Administrators, and Politicians: The Report of the Riehlman Committee	*Edward A. Shils*

Yearly Subscription: $5

BULLETIN OF THE ATOMIC SCIENTISTS
5734 University Avenue, Chicago 37, Illinois (U.S.A.)

THE AGE OF DISCOVERY

To understand the modern world you must keep pace with the progress of science. The only journal providing a running commentary on major scientific developments both pure and applied is

DISCOVERY

Recent contributors include:

Dr. Harrison Matthews, Dr. G. E. R. Deacon,
Dr. D. P. Wilson, Sir Ben Lockspeiser,
E. W. Golding, Prof. A. C. Crombie, N. W. Pirie,
Prof. C. M. Yonge, Derek Wragge Morley,
Prof. S. C. Harland, Dr. J. G. Feinberg, Sir Edward Appleton.

2/- monthly *24/- annually post free*

Specimen copies available from the publishers:

JARROLD AND SONS LTD.,
COWGATE, NORWICH, NORFOLK, ENGLAND